Linguistic Determinants of Performance on Formal Problems

David H. Turner

Ph.D.

1967

Acknowledgements

Dr. A.R.H. Gellatly, University of Keele: for his supervision of the research reported here.

Dr. J. Hartley, University of Keele: for his helpful comments on an earlier version of Chapter 1 of this thesis.

Prof. R.A. Griggs, University of Florida: for providing copies of research papers and his experimental data concerning the THOG problem.

Paul I. Rennie: for collecting the data for Experiments 2 and 3 in this thesis.

Patricia M. Allen: for assistance with preparing the materials and collecting the data for Experiment 4.

Chris Woods: for assistance with the hardware and software involved in the production of this thesis.

My parents and various friends: for support of many kinds.

All the researchers whose work has been mentioned in this thesis.

All those who have taught me; especially the members of the Departments of Psychology and Philosophy at Keele University.

The numerous subjects who participated in the experiments reported here.

ABSTRACT

The research described investigates why subjects frequently give logically wrong answers to problems requiring deductive reasoning. In Experiment 1 a pattern of erroneous responses to Wason's selection task which has commonly been attributed to verification bias is shown to be due to a form of matching bias (higher-order matching) which takes account of negation. This form of matching is shown to be associated with binary problem content.

In Experiments 2 and 3 it is shown that responses are sometimes made on the basis of salient problem features when a logical task is of only moderate difficulty. This suggests that, contrary to a widely held view, matching may not be a fall-back strategy in response to logical difficulty.

Experiment 4 demonstrates that comprehension may be based on pragmatic features of sentences, rather than their grammatical structure. It is argued that subjects might comprehend the selection task in this way, and be unaware of its logical structure and difficulty. Independent evidence using conditional reasoning problems is described in support of this conclusion.

In Experiment 5 subjects frequently formulate a potentially conditional truth-function in a conjunctive form to which higher-order matching yields correct responses. The reason for previous experimenters' failure to observe facilitation with conjunctive formulations of the selection task is demonstrated in Experiments 6, 7 and 8.

It is argued that errors on the THOG problem are due to a form of matching bias. In Experiment 9 some facilitation is observed on a plausible version of the THOG problem, possibly because the disjunctive rule was not stated. In Experiment 10 conjunctive formulation is also shown to considerably improve performance. It is argued that conjunctive formulation cues a more complete representation of the premises and an effective solution strategy of a kind which has not previously been suggested.

CONTENTS

CHAPTER 1

INTRODUCTION

The purpose of this chapter is to introduce the areas of theoretical debate which have a bearing on the research to be reported. These will include general theories of reasoning and narrower hypotheses concerning the determinants of performance on specific problems. The relation between theory and research will be discussed, as will the relation between some general theories and some particular hypotheses. A further aim is to describe empirical findings which have lead researchers to accept or reject various hypotheses and to discuss alternative interpretations of the experimental data.

Two theories of reasoning, and their role in the present research

The research to be reported in this thesis is concerned with certain aspects of comprehension and reasoning. The principal focus is on linguistic comprehension and deductive reasoning. In this section of Chapter 1 two theories of reasoning will be briefly outlined in order to introduce some of the concepts which will be used later in describing my own research. In addition, a broad comparison of these two theories will serve to indicate the nature of current theoretical positions with regard to research in this area. At this stage it is not intended to offer any empirical evidence for the correctness or otherwise of the theories, but simply to present a broad outline of what they suggest. Later in this section the relevance of theory to research will be discussed. It will be concluded that commitment to any particular theory, or to its falsification, is often a less than optimal position to adopt in undertaking psychological research in many areas, including the present one.

Comprehension and reasoning can be taken to consist of both relatively slow, conscious processes and rapid, unconscious (and therefore non-introspectible) processes. For example, one might set oneself to read a written passage and be aware that one was gaining an understanding of what the passage meant. This would be an example of a relatively slow process of which one is consciously aware. As a component of this processing one would also be arriving at a particular interpretation of any potentially ambiguous word in the passage. This would tend to be done rapidly and without conscious awareness, so one would not be aware of having considered alternative meanings of such words. This can be illustrated by the use of 'garden path sentences' such as 'The old man's glasses were filled with sherry'. One is not aware of having chosen one of two interpretations of the word 'glasses' (as meaning 'spectacles') until the more plausible interpretation of 'drinking vessels' is suggested by the way in which the sentence is completed. An implicit inference has been made, quickly, automatically and unconsciously, regarding the meaning of the word 'glasses'. Such inferences are frequently invalid (if evaluated by the criteria appropriate to formal logic), but their conclusions are subject to correction on the basis of further information.

Here is a possible source of error in performance on verbally presented problems which require reasoning. Subjects may be making the wrong implicit inferences during the comprehension process. Subsequently they might go on to reason by making deliberate, explicit and valid inferences so as to reach a conclusion which is entailed by the premises as comprehended, although that conclusion might contradict the premises as they were intended to be understood.

Making implicit inferences during comprehension is an unconscious component of the process of understanding what propositions are expressed by the sentences used to communicate the premises of a problem. Until

fairly recently there was considerable general agreement regarding the nature of the processing which follows the formation of this initial propositional representation. Piaget and others (eg; Inhelder and Piaget,1958; Beth and Piaget, 1966) have argued that by the formal operational stage of development a child will have acquired the competence to reason in accordance with the valid inference rules of the propositional calculus of formal logic. The task of reasoning would then amount to selecting the appropriate inference rule suggested by the syntactical form of the premises, and applying it so as to reach a deductively entailed conclusion.

Since an educated adult is supposed to have competence in reasoning which is equivalent to mastery of the complete set of valid inference rules, the only possible source of error in reasoning would be the use of an inappropriate rule. Since the selection of an appropriate rule depends on the perceived syntactic form of the premises, an incorrect selection might be the result of faulty comprehension of the premises, possibly as a result of the salience of pragmatic or contextual features which may distract attention from syntactic ones. Hence implicit inferences concerning the meaning of syntactically important words may lead to an understanding of the syntactic form of a sentence which differs from that intended. For example, a premise of the form 'If p, then q' could be erroneously comprehended as 'p, if and only if q', particularly in contexts where this would be a very plausible interpretation. Were such an interpretation correct, it would be possible to reason validly from the truth of q to the truth of p. However, reasoning in this way about 'If p, then q' is invalid.

If it could be shown experimentally that errors sometimes occur in the computational processes involved in reasoning, rather than in comprehension of the task, this would suggest that subjects had acquired a

defective set of inference rules. Since rationality might be said to be inconsistent with having a defective set of rules, the existence of such errors would suggest that human beings are irrational.

On certain types of syllogistic reasoning tasks, and on Wason's selection task (to be described later), erroneous responses are extremely common. Hence, if the Piagetian view that most adults have the competence to reason according to logically valid inference rules is correct, and if (contrary to the Piagetian view) such errors are not attributable to other aspects of cognitive processing, then one might reject the Piagetian premise above and conclude that humans do not have the logical competence that Piaget attributes to us. However, such a conclusion would be a product of human reasoning, and it may therefore have been reached by logically invalid reasoning. Hence there is no logical justification for accepting this self-defeating conclusion. Piagetian theorists are consequently constrained to reject the second premise: that errors are sometimes due to faulty reasoning. They are able to do this consistently only by constructing their theory in such a way that nothing will count as faulty reasoning. Hence Piagetian theorists, and others who advance theories of competence rather than of performance, are insulated from empirical evidence which could lead to rejection of their theories.

If one is committed to the view that deductive reasoning is essentially the application of the valid inference rules of propositional logic, then there are only two positions which can be taken: either humans are rational and never make errors in reasoning, or humans are irrational and do make errors in reasoning. Since it would be self-defeating to attempt to argue for the second of these alternatives, commitment to the Piagetian view of reasoning is tantamount to commitment to the view that intelligent, educated adults are rational and never make errors in reasoning. Hence Henle (1978), in accepting the Piagetian view, had

little alternative but to interpret subjects' logically unacceptable conclusions in a way which led her to assert: "I have never found errors which could unambiguously be attributed to faulty reasoning".

It has been noted above that an appreciation of syntactic structure is necessary in order to apply logical rules of inference. Greene (1970) has argued that it is impossible to study syntactic aspects of language in isolation, since the only purpose of syntax is to convey "meaning". She showed that the difficulty (measured by response latency) of same/different judgements concerning pairs of sentences depends on whether they differ in meaning rather than on their syntactic forms.

Formal aspects of reasoning behaviour depend on prior appreciation of syntactic features of the premises on which the reasoning is based. If it is impossible to study syntactic aspects of language behaviour in isolation, it is also impossible to study in isolation aspects of reasoning which depend on the syntactic features of the relevant premises. The Piagetian view is that reasoning behaviour can be described entirely in formal terms, and that such a description corresponds to the inference rules of formal logic. This appears to be an empirical claim; but if it is impossible to study these formal aspects in isolation, the claim cannot be tested empirically. To continue the analogy with Greene's (1970) remark about language it could be added that the purpose of logic is to preserve truth; and the truth of a statement depends on what it means. A theory of reasoning is therefore required which takes into account the semantic and pragmatic aspects of reasoning behaviour.

A possible reason for reluctance to abandon the Piagetian view is that until recently no positive alternative was available to challenge it. The situation changed when Johnson-Laird (1983) pointed out the weaknesses of the theoretical position outlined above (which he calls the 'doctrine

of mental logic') and proposed a detailed alternative theory. Johnson-Laird's theory concurs with the doctrine of mental logic only to the extent that the initial comprehension of premises is taken to consist in the formation of a propositional representation of their meaning. According to the doctrine of mental logic, the next step is the application of an inference rule whose selection depends largely on the syntactic structure of the premises. Johnson-Laird denies the existence of any logical rules of inference in the minds of those untrained in formal logic, and argues that reasoning is normally carried out in a way which depends on the semantic properties of the premises. The meaning of the premises suggests an appropriate recursive procedure which is applied to either the propositional representation of the premises or to a set of mental models based on the propositional representation. This set of mental models represents the alternative possible states of affairs which could obtain on the assumption that the premises are true. Thereafter, reasoning consists in executing the recursive procedure of searching for an appropriate single proposition which is true of any mental model in the set. Candidate propositions are tested against the set of mental models in order to detect any contradiction. Any proposition which passes this test will necessarily be one which is implied by the original premises, and it will have been inferred without recourse to any formal rule of inference.

An alternative recursive procedure is sometimes applied to the propositional representation itself, according to Johnson-Laird. This involves the replacement of propositions by their truth-values. For example, given premises of the form 'p or q' and 'not-p', the second premise indicates that the proposition p is false. The value 'false' may therefore be substituted for the proposition p in the first premise, which yields 'false or q'. The presence of the connective 'or' indicates that at least one of the propositions which it connects must be true. Hence it

can be concluded that q is true.

Whether reasoning is carried out in this 'truth-functional' way or by means of the construction of mental models appears to depend on the degree of familiarity and concreteness of the content of the premises. Highly unfamiliar or symbolic content may not offer the richness of meaning required for the construction of mental models. Johnson-Laird (1983) suggests, however, that in most circumstances people tend to use mental models rather than truth-functional reasoning.

Johnson-Laird's theory of mental models is essentially a theory of valid reasoning, although it allows for novel explanations of reasoning errors. For example, in the case of syllogistic reasoning many errors are attributed to the greater difficulty of those figures which require more mental models to be considered. Neither of the theories so far described can have much explanatory value in cases where subjects appear not to respond on the basis of the logical features of a problem, and evidence will be presented later which suggests that incorrect responses to reasoning problems frequently have such an origin.

When responses are made on the basis of non-logical features of a problem, interpretation of such behaviour in the light of either theory may be unhelpful, or even misleading. These theories suggest certain ways of interpreting erroneous responses; for example, both theories suggest that it is important to decide whether subjects are forming adequate propositional representations of the premises. However, neither theory gives an account of the variables which determine whether a subject will reason logically (whatever detailed procedures this involves) or on some other basis. The doctrine of mental logic avoids this question by suggesting that reasoning is always logical, hence it is always appropriate to seek explanations of errors in areas other than the

reasoning process itself. On the other hand, the mental models approach allows for the possibility of errors which are due to the cognitive overload which may be imposed by the task of constructing and evaluating a full set of mental models. Both theories emphasize an approach to the explanation of errors in terms of defective performance in executing the cognitive processes normally involved.

Forming any degree of commitment to either of these theories, or even to the task of deciding between them, involves some risk of losing sight of the possibility that non-logical processes may be cued by experimental stimulus material. To emphasize the formal or semantic aspects of reasoning may be to distract attention from its pragmatic aspects, which may prove to be equally important. In everyday experience elements of a situation may cue us to avoid or postpone deductive reasoning and seek further information. This may be achieved by direct observation which could confirm or disconfirm something which we could have deduced to be true or false. Alternatively such situations could cue us to ask an appropriate question, the answer to which would be as informative as direct observation. When an experimenter expects responses to be made on the basis of deductive reasoning, this expectation can induce a bias towards explanation of errors in terms of 'faulty reasoning' or 'faulty comprehension' when, in fact, an alternative kind of processing may have been cued by the pragmatic features of the stimulus material and executed faultlessly.

The bias which may be attendent on theoretical commitment can extend to the design of experiments as well as to the interpretation of results. This has been pointed out by Greenwald et al (1986) who give examples of research projects in which, they argue, theory has obstructed progress. They suggest that this tendency is avoided most effectively by regarding research as an attempt to discover under what conditions a given effect

occurs. This approach may lead to the identification of important independent variables which have not been considered in connection with any existing theory. It is an approach which comes closest to characterizing the method adopted in carrying out and reporting the present research. The main question to be addressed here may be formulated in the way suggested by Greenwald et al (1986) as; "Under what conditons do educated adults fail to give correct responses to formal problems?".

The scope of the research to be reported

The main paradigms used in the present research are Wason's selection task and THOG problem. These paradigms are particularly appropriate to the aim of the research, since they tend to elicit a considerable proportion of erroneous responses. The nature of such errors can be informative regarding the ways in which features of the tasks give rise to the cognitive strategies responsible for these errors.

Wason's selection task

Experiments using Wason's (1966) selection task typically begin by informing subjects that a pack of cards has been prepared, each of which has a letter on one side and a number on the other. Subjects are then shown a set of four cards which are said to be taken from that pack and show on their uppermost sides, for example, the symbols 'B', 'C', '3' and '4'. A written sentence is then shown to subjects, such as "If there is a B on one side of a card, then there is a 3 on the other side".

Subjects are then asked which card or cards they would need to turn over in order to decide whether the written sentence is true or false. It is emphasized that no card should be turned over unnecessarily.

The correct solution is to select only cards which could show the conditional sentence to be false, and any such card would need to have a B on one side and a number which is not 3 on the other side, since this is the only possible counterexample to the conditional sentence. Of the four cards displayed, only the one with a B uppermost and the one with a 4 (not-3) uppermost could satisfy this description of the counterexample, therefore they should be selected.

In order to discuss the selection task briefly and in general terms it is useful to regard conditional sentences such as "If there is a B on one side of a card, then there is a 3 on the other side" as consisting of the 'If, then' relation plus an antecedent "there is a B on one side of a card" and a consequent " there is a 3 on the other side". The antecedent is usually symbolized by 'p', and the consequent by 'q'. Hence the whole sentence is of the form 'If p, then q'. The four cards used may be referred to according to whether they instantiate the affirmation of p (the p card) or its negation (the not-p card), '-p'; and the affirmation of q (the q card) and its negation (the not-q card) '-q'. In some contexts it is also useful to identify the cards, not in terms of what they affirm or negate, but by logical cases. Thus, in this example, the p card instantiates the truth of the antecedent 'TA', the not-p card the falsity of the antecedent 'FA', the q card the truth of the consequent 'TC' and the not-p card the falsity of the consequent 'FC'.

TABLE 1

Three ways of describing card selections when the conditional sentence is: 'If there is a B on one side of a card, then there is a 3 on the other side'.

Symbol on card	B	C	3	4
Proposition affirmed or denied	p	-p	q	-q
Logical case	TA	FA	TC	FC

For any conditional of the form 'If p, then q' the four cards can be described in either of the ways shown in the second and third rows of Table 1 above.

Although the correct solution to the problem is 'B, 4', the majority of subjects select 'B, 3' or 'B' only. Typical selection frequencies, taken from data obtained in four experiments by Johnson-Laird and Wason (1970), are shown in Table 2.

TABLE 2

Card(s) Selected	% frequency
p,q	46
p	33
p,q,-q	7
p,-q	4
Others	10

The verification hypothesis

It is clear that subjects have relatively little difficulty in selecting the correct antecedent card 'p', but tend either to fail to select a further card or to select the incorrect 'q' card. Other frequently observed patterns of selection are 'p, q and not-q' and all four cards. An explanation of all these four patterns of selection has been suggested according to which subjects are said to be trying to verify the conditional sentence instead of adopting the logically correct strategy of trying to falsify it.

The effect of this tendency to verify on subjects' selections is held

to depend partly on their having a defective truth-table for conditionals. The idea that subjects may have a defective truth-table arises from the observation of subjects' behaviour when they are given antecedent-consequent pairs to evaluate in the context of a similar conditional sentence. They are asked to classify pairs of cards as true of, false of or irrelevant to a conditional sentence. Subjects tend to judge the combinations 'FA, TC' and 'FA, FC' to be irrelevant to an 'If, ...then' conditional, although in formal logic these combinations are taken to be true of a conditional relation (Johnson-Laird and Tagart, 1969; Evans, 1975; Evans and Newstead, 1977). It has also been found that when subjects are asked to construct and classify pairs which are true or false of a conditional they fail to construct 'FA, TC' and 'FA, FC' pairs (Evans, 1972).

Johnson-Laird and Wason (1970) suggested that the commonly observed patterns of card selections are a result of subjects' defective truth-tables and their differing levels of insight into the logical structure of the problem. Two factors are involved here: whether the subject tries to verify or falsify or both, and whether the conditional is correctly construed or mistakenly construed as a biconditional of the form 'p, if and only if q'. Accordingly, the choice of the p card alone is said to result from construing the conditional correctly and trying to verify it. The suggested reason for the selection of 'p and q' is a similar level of insight with the conditional construed as a biconditional. Appreciation of the need to falsify a conditional, without the appreciation that there is no need to verify also, produces 'p,q,-q' choices in the context of a defective truth-table (the 'not-p' card being judged to be irrelevant). When the sentence is construed as a biconditional, complete insight (resulting in the use of a pure falsification strategy) would lead to the selection of all four cards. Complete insight with a conditional construal would result in the correct

'p,-q' choice even in the context of a defective truth-table. Hence the defective truth-table is not itself a source of error, but leads subjects to avoid selecting the incorrect 'not-p' card when attempting to verify the conditional sentence, so construed.

If this interpretation of subjects' behaviour on the selection task is correct, it would appear that an error of reasoning is occurring even on those occasions when the conditional has been correctly comprehended. In particular, the common failure to select the 'not-q' card might suggest that subjects have an incomplete or defective set of inference rules. From this observation, as argued above, it is a short step to the self-defeating conclusion that humans are irrational. This point has been debated extensively in Cohen (1981) and the responses to Cohen's paper (published together with it).

From a less theoretically committed position it can be argued that it has been shown only that subjects tend not to use the logically correct falsification strategy. However, it does not follow that subjects are verifying or using any other kind of logical (if inappropriate) strategy. They may be responding on a non-logical basis. This is the contention of the matching hypothesis which is becoming widely, although not universally, accepted. Later in this chapter reasons will be suggested why some researchers have accepted the matching hypothesis without abandoning the verification hypothesis.

Matching Bias

Evans (1972) and Evans and Lynch (1973) suggested that subjects' selections are determined not by a verification bias but by a matching bias. According to this hypothesis p and q are commonly selected because subjects match their selections to the symbols named in the conditional

sentence. In order to compare the predictive accuracy of this hypothesis and the verification hypothesis, negation may be introduced into the conditional sentence. This makes possible the four forms of conditional shown in Table 3, together with the logical status of the four cards concerned.

TABLE 3

Form of conditional	Logical status of card			
	TA	FA	TC	FC
If p, then q	p	-p	q	-q
If p, then -q	p	-p	-q	q
If -p, then q	-p	p	q	-q
If -p, then -q	-p	p	-q	q

The verification hypothesis predicts that subjects will tend to select TA rather than FA, and TC rather than FC. By contrast, the matching hypothesis predicts that subjects will select the cards mentioned in the conditional sentence, regardless of whether they are mentioned with or without negation. Subjects will therefore select p rather than -p, and q rather than -q.

Manktelow and Evans (1979), in two experiments, found a significant preference for p over -p, and for q over -q; a result which supports the matching hypothesis. Evans (1983a, 1983b) argues that subjects' preference for p and q is due to the fact that for linguistic reasons they are more likely to perceive as relevant, and therefore to attend to, the matching cases. In natural language negations are used to make denials rather than assertions, and what is denied is likely to be taken to be the relevant topic. Hence the sentences "I went for a walk" and "I did not go for a walk" deal with the same topic. Similarly, the sentences "If the letter is B, then the number is 3" and "If the letter is not B, then the

number is not 3" both appear to be about 8 and 3. The judgement that only 8 and 3 are relevant to the sentence results in attention being paid to only those cards on which these symbols are visible; hence those cards are the only candidates for selection. However, this linguistically based relevance heuristic may combine with a directional heuristic, which is also linguistically based, to determine how the 'If p, then q' wording of the conditional sentence is interpreted.

Directional Bias

The linguistic origin of directional bias can be understood and tested by comparing two different ways of wording a conditional sentence. The 'If p, then q' wording (IT) emphasizes that p is a sufficient condition for q. For example, the sentence "If he is a policeman, then he is over 5' 9" in height" suggests the inference from 'He is a policeman' to 'He is over 5' 9" in height'. This form of inference is known as 'modus ponens' (MP). In sentences of this form the most relevant information on which to base a conclusion is the truth or falsity of the antecedent. This is to be contrasted with the 'p, only if q' (OI) form of conditional wording which, while logically equivalent to 'If p, then q', emphasizes that q is necessary for p. Hence "He is a policeman only if he is over 5' 9" in height" suggests the modus tollens (MT) inference from 'He is not over 5' 9" in height' to 'He is not a policeman'. The apparently most relevant information here would therefore be whether the consequent is true or false.

The differences in the frequency of forward and backward inferences predicted by the directional hypothesis has been tested (Evans, 1977; Evans and Beck, 1981; Rips and Marcus, 1977; Roberge, 1978). It has been consistently found that subjects make more MP than MT inferences on IT worded conditionals, whereas they make significantly more MT than MP

inferences on OI worded conditionals. Evans (1977) used the four forms of conditional sentence shown in Table 3 above and the four corresponding OI forms. He found that the numbers of invalid 'denial of the antecedent' (DA) inferences remained at 38% on both IT and OI forms. By contrast, MP inferences were endorsed in 100% of cases in the IT forms and 76% of cases on the OI forms. Hence one effect of the IT wording is that it raises the probability that inferences will be made on the basis of an antecedent card rather than a consequent card. In the selection task this effect would explain the fact that many subjects select only an antecedent card. The IT wording also raises the probability that inference made will be a valid MP rather than an invalid DA inference. This would lead to selection of the TA card in preference to the FA card. It can be seen that this latter effect of IT wording would tend to counter the effect of matching bias on variants of the task with a negated antecedent. It would tend to give rise to selections of the 'not-p' card, while matching would result in the selection of the p card. Hence on IT worded variants with negated antecedents, selection of the p card rather than the 'not-p' card would indicate the effect of matching bias is greater than that of directional bias. Matching responses to negated antecedents will therefore be less predominant than matching responses to negated consequents, since in the latter case there is no directional tendency to select the TC card (ie; the 'not-q' card) rather than the q card.

An explanation of this kind is required to reconcile with the matching hypothesis another finding of Manktelow and Evans (1979). They found a significant preference for TA over FA, a result which could be claimed to support the verification hypothesis. However, contrary to the predictions of the verification hypothesis, they found no significant preference for TC over FC. When allied with matching bias, directional bias can explain this anomaly and it can also explain other patterns of

selection which have been taken to indicate the employment of a falsification strategy. On doubly negated conditionals, 'If not-p, then not-q' and also on the singly negated 'If p, then not-q', the correct selection may be made as a result of directional bias towards the selection of TA, and pure matching bias in the consequent card selection of q rather than not-q.

The combined effects of biases

The main point to be made at this juncture is that the matching and directional biases, together with consideration of other possible non-logical bases of responding, can potentially explain the commonly observed selections on positive IT conditionals as well as can verification bias and conditional or biconditional interpretation. Selection of p alone may be due to matching and directional bias. Selection of 'p and q' may be due to pure matching. All four cards may be selected as a 'safe' option which ensures that no correct selection is omitted. While if only one selection were omitted it would tend to be the not-p card, since both directional and matching biases would induce subjects to ignore it. In which case they would select the remaining p, q and not-q cards.

The evidence with regard to the range of influence of these two kinds of bias appears to be equivocal. Some versions of the selection task elicit mainly matching responses, some elicit responses which seem to be principally influenced by verification and others seem to suggest that both biases are present. It has been suggested (Reich and Ruth, 1982) that kind of bias observed depends on the thematicity of the problem, with more thematic content eliciting more verification responses. For example, in Reich and Ruth's (1982, Experiment 2) highly thematic versions of the task, they attributed the observed responses, almost exclusively, to

verification. On the other hand, Yachanin and Tweney (1982), using thematic problems, found evidence for both matching and verification.

On the basis of evidence of this kind most researchers in the area, while accepting the plausibility of the matching hypothesis, have been reluctant to abandon the verification hypothesis. There has been little pulished research into selection task performance since 1983, and the majority of researchers in the early 1980s (with the prominent exception of Evans) were interpreting their results in terms of verification bias, among other factors. For example, Reich and Ruth (1982) treat verification, falsification and matching as alternative bases on which subjects might respond in differing circumstances. Griggs and Cox (1983) consider which of these strategies best explains the data from each of their experiments; while Krauth (1982) treats them as contributary components in a statistical account of responding. Significantly, Krauth (1982) found it necessary to introduce a verification component into his statistical theory in order to explain his results.

While verification and falsification presuppose a mental logic through which these strategies can be applied, the matching hypothesis suggests that responses are due to non-logical, linguistic processes. Viewed as contributary factors, it is difficult to see how these strategies might collectively determine the responses of an individual subject. It will be argued later that the correct approach is to regard verification and matching as competing explanations of experimental data. Griggs and Cox (1983) took this approach, but were unable to draw a firm conclusion as to which explanation was to be preferred. It will be argued that such results have turned out to be equivocal because all hypotheses so far considered have been inadequate, although the matching hypothesis is correct, except in the claim that negation is always ignored. The explanation of differing response patterns offered by Reich and Ruth

(1982), that subjects use different strategies which are affected by the thematicly of a problem's content, depends on a particular view of matching as a 'last resort' strategy which will be considered in the next section and opposed throughout this thesis.

The situation may become clearer in the light of a more detailed understanding of the origin of matching bias. On the one hand it may be a last resort when any logically based response is too difficult to make. On the other hand it may be a basis of responding which subjects use more readily than any logical strategy as a result of the entrenched mechanisms of linguistic comprehension. The question of whether either of these views is correct will be addressed in the present research by investigating the conditions under which matching responses, and other 'non-logical' responses, occur. In order to introduce this aspect of the research the arguments and evidence to date will now be summarized.

The origin of matching bias

Johnson-Laird and Wason (1977) argued that matching may be a form of response which is peculiar to extreme bafflement, or lack of appreciation of logical structure. Manktelow and Evans (1979) also suggested that matching may be a last-resort strategy when subjects have no other basis for responding. Yachanin and Tweney (1982) suggest that both matching bias and verification bias may be "cognitive short-circuiting strategies" which reduce the cognitive load presented by the standard abstract forms of the selection task. Clearly matching bias allows a consistent basis for responding without the need for any logical processing; and verification bias avoids consideration of two hypotheses, that the conditional sentence is true and that it is false, in favour of the one hypothesis that it is true.

This 'cognitive short-circuiting' interpretation appears to depend on the assumption that subjects are attempting to respond logically in the first instance. The argument continues to the effect that the logical complexity of the problem sometimes baffles subjects to such an extent that they are able to respond only on the non-logical basis of matching. Evans (1983a, 1983b) takes a contrary view which will be argued for here and in later chapters. This is the view that the selection task tends to elicit relevance judgements as part of normal linguistic processing, and that these are responsible for the observed matching responses.

An explanation of matching bias which is consistent with the verification hypothesis and the doctrine of mental logic is that subjects always become aware of the syntactic form of a problem, although in the selection task they tend to interpret the conditional as a biconditional. Subjects are also assumed to have sufficient logical competence to solve the problem, although it would appear that they do not have the appropriate metacognitive skill to adopt the correct falsifying strategy, and tend instead to adopt a verifying strategy. When subjects are presented with versions of the problem which baffle them as to how to verify the conditional correctly, they have to resort to responding on the basis of matching bias.

An alternative non-linguistic explanation of matching, and of other features of performance on reasoning tasks, has been put forward by Pollard (1982). He argues that on realistic versions of the task subjects' responses are determined by the relative availability of associative links between the problems' content items. These links are held to exist as a result of previous experience with similar items and contexts. With abstract content the presence of salient cues in the presentation is believed to be responsible for the selections. These

features of a problem determine which of the selection alternatives are attended to by subjects: the alternatives attracting greater attention being more likely to be selected. Evans (1983) concurs to the extent that selective attention may be important in mediating correct selections, such as that of the TA card when the antecedent contains negation. Selective attention may also be involved in the mediation of superior reasoning performance. In constructing an accurate representation of a verbally expressed problem it is important that unemphasized features of it be considered for inclusion. It is also important that all possible counterexamples to a candidate conclusion should be considered.

The conditions under which matching responses occur have been considered by Johnson-Laird and Wason (1977a) who pointed out that on a disjunctive version of the task used by Wason and Johnson-Laird (1969), matching to both of the named items occurred in only 19% of responses. The task required subjects to select cards which could prove the truth (or falsity) of a sentence like 'Every card has a square which is black on one side, or a line which is crooked on the other side'. The cards showed a black square, a white square, a crooked line and a straight line. The most frequent response (75%) was the correct double mismatching case; 'white square and straight line'.

Johnson-Laird (1969a) based an explanation of this result on his finding (Johnson-Laird, 1969b) that subjects who had gained insight into a logical task tended to lose it when the task involved comprehension of a more complex description, and to regain it when simpler descriptions were subsequently presented. He attributed the loss of insight to the difficulty of understanding the sentence concerned. In the case of the selection task, he argued that the greater linguistic complexity of 'If p, then q' compared with 'p or q' appears to be one of the factors which give rise to matching responses, due to the loss of logical insight engendered

by that complexity. This linguistic explanation is supported by the observations of subjects' performance on tasks with differing linguistic formulations but identical logical features.

The relation involved in the conditional selection task in its 'If not-p, then q' variant has the same truth-table and logical properties as 'p or q' (understood inclusively), and therefore both of these statements have the same counterexample (-p & -q). Despite their identical logical properties, the former commonly elicits the responses associated with matching bias while the latter rarely does so. Even when such responses to the disjunctive task do occur it is not clear that they are the result of matching bias rather than the result of validly deriving a second counterexample (p and q) to an exclusive interpretation of the disjunction. The main point is that, apart from this possibility of exclusive interpretation of the disjunction, these two forms of words are logically identical. Hence the responses to the conditional selection task cannot be attributed to its logical difficulty in any formal sense. The phrase 'logical difficulty' can also be taken to refer to the difficulty of carrying out the cognitive operations required to generate a logically correct solution. However, such an interpretation of the phrase robs it of any explanatory power. What is required is a description of the cognitive operations concerned and of how they differ between the conditional and disjunctive forms. To this end an independent variable must be identified which is such as to make a difference in the difficulty of these two forms of the task.

There are two differences between conditional and disjunctive wording which appear to support the 'linguistic difficulty' hypothesis. First, the words 'If..., then...' and '... or ...', when used in formal logic, are treated as sentence-forming operators on sentences (Lemmon, 1965, p.6). In the case of both 'If p, then q' and 'p or q', formal logic

requires p and q to be sentences. By contrast, it is common in natural language for p and q to be single words in the cases of 'p and q' and 'p or q'. For example, it is correct to say 'You may have coffee or tea' or 'You may have coffee and tea'. There is, however no analogous grammatical utterance which contains the form 'If coffee, then tea' without expanding 'coffee' and 'tea' into propositions as in 'If you have coffee, then you may have tea'. The semantics of 'and' and 'or' determine the relation between p and q. However, as just remarked, in natural language 'If p, then q' requires p and q to be sentences. Relations between sentences may be complex, causal or intentional relations. Hence there is no simple semantic criterion of validity for 'If p, then q'. In the case of 'p and q' and 'p or q', p and q may sometimes be sentences, but if they have the same subject they are easily converted to, and understood as, relations between predicates. For example, 'The letter is B or the letter is C' can be converted to 'The letter is B or C'.

A second difference between these two linguistic forms is that the semantic simplicity of 'p or q' renders it easily understood in a truth-functional way. It is readily apparent that it is made true by the truth of p and by the truth of q. It is even more readily apparent that it is made false by the falsity of both p and q, whether it is understood inclusively or exclusively. The availability of a counterxample serves as a good test of the truth-functional comprehensibility of a sentence with abstract content. This kind of comprehension makes possible what will be called 'direct' inferences about 'p or q' by making direct use of semantic composition (Johnson-Laird, 1983, p.49). Reasoning in this way has been described above as the substitution of truth values for the constituent propositions, p and q. Hence when both p and q are false, 'p or q' is converted to 'false or false'. Semantic knowledge of 'or' indicates that its use is appropriate only if (at least) one of the constituent propositions is true. This enables one to conclude, from purely semantic

considerations, that the whole complex proposition 'false or false' is necessarily false.

The status of the semantically more complex 'If p, then q' is very different in this respect. People do not usually appreciate that when p is false it follows that 'If p, then q' is true. Nor do they appreciate that when q is true it follows that 'If p, then q' is true. Instead they try to make sense of 'If p, then q' via an understanding of the intentional or causal relations between p and q (Johnson-Laird, 1983, p.52). By contrast with the disjunctive selection task, the conditional selection task does not permit subjects to make direct inferences to the counterexample. These considerations suggest that the lack of a means to make direct inferences to the counterexample may lead to an attempt at comprehension via judgements of relevance, when content and context suggest no richer relation between antecedent and consequent. The lack of a route to comprehension via direct inference must surely have some negative effect on comprehension, and the relevance judgements associated with matching bias appear to be the result.

Importantly, Griggs and Cox (1983) have sought empirical evidence for the cognitive short-circuiting view of matching, which attributes it to logical rather than linguistic complexity. They compared performance on four versions of the selection task. Two of these were thematic versions of the problem which are known to produce facilitation. The other two were abstract versions with different types of content; recodable and non-recodable. The recodable content included items such as 'vowel' and 'even number' which when negated are easily recoded into positive form; 'consonant' and 'odd number'. The non-recodable content items were specific letters and numbers such as 'B' and '3'.

They found that matching bias was predominant only on abstract

versions with non-recodable content items; and that this was apparent only when frequencies of choice for each logical alternative (TA, FA, TC and FC) were considered.

This method of identifying matching bias was first devised by Evans and Lynch (1973). Their criteria are:

(1) more TA selections on conditionals with a positive antecedent than on those with a negative antecedent;

(2) more FA selections on conditionals with a negative antecedent than on those with a positive antecedent;

(3) more TC selections on conditionals with a positive consequent than on those with a negative consequent;

(4) more FC selections on conditionals with a negative consequent than on those with a positive consequent.

However, when the selected combinations of cards were considered Griggs and Cox found equal frequencies of matching and verification. These were the most frequent response types on abstract problems, but were much less frequent than logically correct response types on the facilitatory thematic problems. On the grounds that their thematic problems with familiar content elicited many correct responses, Griggs and Cox (1983) conclude that "... matching and verification bias are cognitive short-circuiting strategies that will be abandoned when problem content cues in familiar knowledge from memory ...". Here the authors appear to suggest that when the content is familiar there is no attempt at formal reasoning, and therefore no possibility of failure due to 'logical difficulty'. Familiar material directly cues a strategy based on memory of similar situations.

Although Griggs and Cox apparently disagree, it seems possible that matching is also directly cued in response to other features of the

problem's content. The availability of a seemingly appropriate relevance heuristic may prevent any attempt at the more detailed linguistic analysis required for a formal solution.

An apparent argument against the view that matching occurs without a prior attempt at a formal solution is that verification bias would not be observed if this were the case. In experiments where verification bias is allegedly observed, the subject is taken to be attempting a formal solution and persisting with an inadequate performance of such formal reasoning. If the verification hypothesis is correct, then it would appear that matching would occur only after a completely abandoned attempt at a formal solution. If, on the other hand, subjects do not commonly use a verification strategy, then there would be little evidence to suggest that they attempt any kind of logical strategy based on either verification or falsification. This, in turn, would suggest that matching is directly cued by linguistic complexity as opposed to being a response to logical difficulty. Evidence that subjects do not attempt to verify the conditional would also remove the last vestiges of support which the selection task data may be taken to give to the doctrine of mental logic. If subjects neither falsify nor verify, then there appears to be no evidence for the use of a strategy based on a logic in the mind.

Content effects in the selection task

In addition to the investigation of linguistic effects in reasoning, which is the main topic of interest in the present research, the selection task has been extensively used to investigate the effects of content on reasoning. In particular, much research effort has been expended in testing the hypothesis that realistic or thematic content facilitates performance. This research impinges on the present topic in the sense that linguistic factors such as familiar wording, in addition to familiar

content items, may facilitate performance. It may also be necessary to distinguish between content effects and linguistic effects in versions of the selection task which have been found to result in superior performance. This topic will be considered after the experimental background has been outlined.

The earliest indication that thematic content could facilitate performance on the selection task was obtained in an experiment by Wason and Shapiro (1971, Experiment 2). Subjects were shown four cards with the name of a town on one side and a means of transport on the other. They were then asked which of the cards they would need to turn over in order to decide whether the claim expressed by a sentence such as "Every time I go to Manchester I travel by car" was true or false. In the control condition an abstract, universally quantified sentence was used, such as "Every card which has a D on one side has a 7 on the other". This condition elicited 2 out of 16 correct solutions while the thematic version elicited 10 out of 16.

Subsequently, Johnson-Laird, Legrenzi and Legrenzi (1972) presented subjects with an array of envelopes and asked them to pretend that they were postal workers and to determine whether a regulation such as 'If a letter is sealed, then it has a 50 lire stamp on it' was violated. Of the 48 responses, 39 were correct. This study was replicated by Golding (1981) with subjects over the age of 45, who may have remembered a similar British postal regulation which ceased in 1968. These subjects gave 13/22 (59%) correct responses. A group of subjects under the age of 45 gave only 2/22 (9%) correct responses. Hence it appears that the facilitation observed here depends on experience of the relevant rule, or a similar one.

There have been several published replications of the Wason and

Shapiro (1971, Experiment 2) study. In one of these Bracewell and Hidi (1974) observed considerable facilitation (75% correct) in the thematic condition; but this may have been because subjects were told that the relevant rule was not reversible. This instruction did not, however, facilitate performance on an abstract problem (8.33% correct). Furthermore, when the order of clauses in the thematic conditional was reversed, "Every time I go to Ottowa, I travel by car" being changed to "I travel by car every time I go to Ottowa", the latter version elicited only 16.66% correct responses. It therefore appears that the facilitation observed was due to an interaction between the non-reversibility instruction and the form of wording used in the thematic version. Lesser degrees of facilitation were observed by Gilhooly and Falconer (1974), with 22% correct solutions in the thematic condition, and by Pollard (1981), with 33.1% (4/12) correct on the thematic version and 0/12 correct on the abstract version. Van Duyne (1974), using universities and major fields of study as content, observed 58% correct responses on a conditional version of the task, and 50% correct on a universally quantified version.

By contrast, Yachanin and Tweney (1982) obtained only 1/80 correct responses using as content campus locations and modes of transport. Brown et al (1980) and Griggs and Cox (1982) also failed to find any facilitation on problems concerning towns and means of transport.

Finally, Manktelow and Evans (1979) found no facilitation using items of food and drink as content.

Hence there appears to be no reliable effect of the inclusion of concrete items in the problem. Where contrasting results have been obtained it is usually possible to argue, as does Griggs (1983), that the content items in the facilitatory version were such as to cue memory of a

prominent counterexample to a familiar relation between them. For example, one of the conditionals on which Van Duyne (1974) observed facilitation was "Every student who studies physics is at Oxford". The selection alternatives associated with this conditional were Physics, Spanish, Oxford and Cambridge. However, Cambridge has a high reputation for physics, of which fact the experimental subjects (undergraduates at University College, London) would probably have been aware. Hence the counterexample of Physics and Cambridge could have been cued by memory. Similarly, the other facilitatory conditional was "If a student studies philosophy then he is at Cambridge", with the selection alternatives of Philosophy, Physics, Cambridge and Oxford. This conditional also has a prominent counterexample; subjects would probably have known of Oxford's high reputation in philosophy, and Oxford and Philosophy is the counterexample to the quoted conditional. Yachanin and Tweney's (1982) failure to replicate Van Duyne's findings can be explained by the fact that they did not use conditionals with well-known counterexamples.

The studies using towns and modes of transport as content are unlikely to have generally well-known counterexamples. However, it is possible that the facilitation observed is a result of the use of content items which are plausible or familiar in subjects' experience. This possibility is strong enough to justify scepticism regarding the effects of thematicity as such, unless the thematic problems concerned are designed in such a way as to eliminate the possibility of memory-cuing. After memory cuing was suggested by Manktelow and Evans (1979) experimenters appear to have avoided using content which could elicit this form of facilitation. Subsequent research has yielded only one published instance of a replication of the thematic content effect (Pollard, 1981) with a smaller effect (33% correct), and with a small (12 subjects) sample. During the same period there have been several failures to replicate the effect using towns and modes of transport and other types of

content (Brown et al, 1981; Golding, 1981; Griggs and Cox, 1982; Reich and Ruth, 1982; Yachanin and Tweney, 1982). Hence it appears that thematicity alone does not produce facilitation.

Facilitatory versions of the problem have tended to include conditionals in the form of regulations familiar to subjects, such as those used in the original Johnson-Laird et al (1972) study and Golding's (1981) replication with older subjects. Similarly, performance is greatly facilitated on the Drinking Age Problem used by Cox and Griggs (1981), where a Florida law known to the subjects was used: "If a person is drinking beer, then the person must be over 19". The facilitation observed on such problems is most plausibly explained (Griggs and Cox, 1983) by supposing that subjects are cued by memory of the rules involved, or analogous rules, together with their counterexamples.

Experience of the precise rule involved is not necessary, since D'Andrade's 'Sears problem' (replicated by Mandler, 1980 and Griggs and Cox, 1982, 1983) is highly facilitatory even though it involves a rule which would not have been directly experienced by subjects. The participating subjects were asked to imagine that they had the job of checking sales receipts at a Sears store, and were told "...to make sure that any sale over $30 had been approved by the section manager"; the approval being indicated by a signature on the back of the receipt. This particular form of word is not necessary for facilitation. Griggs and Cox (1983) used the conditional sentence; "If a purchase exceeds $30, then the receipt must have the signature of the department manager on the back". In both of these versions of the experiment subjects were then shown four receipts, two face up showing amounts of $75 and $25 respectively, and two with the other side uppermost, one with a signature on it and one without. In two such experiments using the second formulation described above Griggs and Cox (1983) obtained a total of 32/40 correct responses.

Subjects would not need to have experience of checking receipts in order to appreciate the nature of the counterexample, a receipt for over $30 with no signature on the back. The familiarity of the general relation between the items, more important and valuable transactions being more likely to require authorization, would suffice to cue the counterexample; or as Griggs (1983) puts it, subjects may reason by analogy from experience with similar rules.

Griggs (1983) has objected that these reliably facilitatory versions of the task all require reasoning from a rule to a required course of action, which seems to be a psychologically different process from the original task of reasoning about a truth-functional statement. In the former case the rule is assumed to apply, it has no truth-status as such, and the task is to ensure that it has been obeyed. In the latter case a universal generalization (expressed by the conditional sentence) may be true or false, and appropriate evidence must be selected on which to base a decision about its truth status. Hence, in the former case, not only may the counterexample be available from memory due to the familiar content of the rule, but also the action-guiding nature of the rule may initiate a search for that counterexample. Therefore, presentation of the problem in a form which includes a procedural rule may be a necessary condition for substantial facilitation. This kind of wording may suffice to cue a search for a counterexample to the rule, which will be found if the rule is familiar or of a familiar kind. It is therefore possible that the substantial facilitation observed on the Sears problem and its like is not an effect of content as such, but of content in the context of a somewhat altered problem.

More recently Cheng and Holyoak (1985) and Cheng et al (1986) have used semantically differing descriptions of the task. These included tasks which incorporated a rule giving permission for an action (named on

the p card) only when a certain precondition (named on the q card) is satisfied. On such rules of the form 'If you wish to do p, then you must first make sure that q', they observed significantly more correct responses than when the relation was presented in a causal or truth-functional guise. It seems that when the task is presented in this form subjects tend to ensure that the action has not been carried out without the required permitting precondition being satisfied. Hence they tend to select the cards which could indicate that the rule has been violated: that the action 'p' has occurred without permission 'q' (ie; when 'not-q' is true). The Sears problem therefore appears to be facilitatory because it is a case of this kind: acceptance of a receipt for over $30 requiring permission indicated by the manager's signature. Cheng et al (1986) suggest that subjects' performance is determined by "pragmatic reasoning schemas" acquired through experience with instances of the the relevant kind, rather than by the use of syntactically based inference rules. Cheng and Holyoak (1985) demonstrated that training using pragmatic rules and examples produced facilitation which was significant when either was used alone, and greater when both were used. By contrast, training in the truth-functional logic of conditional syntax produced no significant facilitation in performance on the selection task.

Although this evidence suggests the predominance of pragmatic factors in reasoning, it does not necessarily follow that pragmatic schemas in the form of inference rules are involved. It may be that experience with scenarios involving permission, for example, produce an outline idea of what such scenarios tend to have in common: a permission 'frame', to use Minsky's (1977) terminology. This outline structure may then be completed by substituting the content items in the problem under consideration. This would provide a mental model of the problem, which could be used to reach a solution as described earlier. Where realistic problems are less facilitatory, this could be because the scenario is not of a familiar

kind, and subjects therefore lack a suitable frame; hence they may resort to making relevance judgements. Alternatively, the most strongly cued frame may not reflect, for example, the conditional structure of the problem. It may be that an incomplete frame is cued which has slots for an antecedent and a consequent, but not for their negations. This idea prompts the further suggestion that the concept of a frame may be psychologically implemented as a mechanism of selective attention of the kind suggested by Pollard (1982). It may take the form of a complex of associative links generated by experience with similar material. The use of such a frame could refine the ability to direct attention to those features which have turned out to be important in the past. Hence where relevant areas of experience are cued, the problem is more likely to be represented accurately and completely, and the representation is more likely to be systematically interrogated. However, when the task fails to cue a suitable frame a 'default' frame may be cued which generates relevance judgements.

The use of frames as opposed to inference rules allows attentional control over the items which are included in the representation of a problem. The presence of 'slots' in the frame (in Minsky's terminology: 'unassigned terminals') would initiate a search for something to fill them. This possibility does not arise on the inference rule view, since the information currently represented determines which rule is to be used. Frames therefore allow problems to be solved via the assignment of subgoals (eg; Wickelgren, 1973, Chapter 6). A frame may be extended by the attachment of a subframe which generates the missing information from available information, thus completing the input to the main frame. Inference rules appear to lack this attention-directing property.

Proponents of the doctrine of mental logic have argued that familiar content is facilitatory because subjects use information which is not

explicitly included in the premises of a problem in order to solve it. Experiments such as that of Golding (1981) suggest that subjects do use knowledge of familiar counterexamples (in the case of Golding's experiment, the fact that an envelope bearing a lower value stamp must not be sealed) in solving the problem. In cases such as the 'permission scenario' problems of Cheng and Holyoak (1985) it is possible that subjects are cued to use the more general knowledge that it is important not to act without the required permission.

The view that computation is influenced by content is also advocated by proponents of the doctrine of mental logic (eg; Rips, 1986). They point out that a context involving mechanical causation, for example, may cue the use of rules of inference belonging to a causal logic, rather than truth-functional rules of inference. In the case of the Cheng and Holyoak (1985) 'permission scenario' problems, it could be argued that anyone who has the concept of permission also has the inference rules of a 'permission logic' available for use when cued by an appropriate context.

Hence an important question which is raised by the phenomenon of facilitation by content is whether content influences the representation of a problem, the performance of computations on that representation or the use of additional information. The previously suggested idea that the use of a suitable frame may be cued by realistic content is consistent with all three of these alternatives. A frame, in addition to cuing a certain kind of representation, also lends itself to certain computational routes to a solution rather than others and contains implicit information concerning what items would be relevant to a solution. This suggestion is more compatible with the mental models view of reasoning than with the doctrine of mental logic. (Johnson-Laird (1983), in the concluding section of Chapter 15, gives examples of forms of procedure that could play a part in thinking by the mapping of propositional representations

into models. A frame would be a special form of procedure which determines the structure of a model).

Frame theory also permits an alternative explanation of commonly observed patterns of inference such as modus ponens which may suggest the existence of inference rules in the mind. A frame which is frequently cued by a particular topic or form of words could lead to the building of isomorphic models from which a similar type of information would tend to be extracted. Such frequently used procedures would have effects which could have led researchers to mistake regularities for the application of rules.

Summary and Discussion

Two hypotheses concerning performance on Wason's selection task have been discussed: the verification hypothesis and the matching hypothesis. It was argued that, for positive IT conditionals, responses which have been explained in terms of verification bias can also be accounted for in terms of matching bias in conjunction with directional bias. The evidence when negation is included has been seen to be equivocal. Most versions of the task elicit some responses which indicate first-order matching and others which have been attributed to verification. One aim of the present research was to try to resolve this equivocation.

From the way in which the verification hypothesis has been described it should be apparent that it shares a conceptual basis with the doctrine of mental logic. It presupposes that subjects have a repertoire of rules of inference, and explains errors as a result of their being cued by the task to select one which can be used to verify the conditional relation. However, the phenomenon of verification itself presents a challenge to the rational underpinnings of the doctrine of mental logic. This conflict

occurs because the existence of errors resulting from verification suggests that subjects' mental logic is imperfect because they use a rule which can only verify the conditional statement when they ought logically to be attempting to falsify it. On the basis of this view of subjects' performance it has been argued that people are irrational (see Cohen, 1981). This is an unacceptable conclusion because it undermines the reasoning process which leads to it.

The view that matching is a short-circuiting response to logical bafflement also implies acceptance of the doctrine of mental logic. According to this view matching occurs only when a problem proves to be too difficult for the 'logic in the mind' to produce a solution. In other words, the failure of a logical and syntactically based strategy forces subjects to fall back on a strategy based on pragmatic and semantic considerations.

According to this cognitive short-circuiting view of matching, the difficulty of the task ought to depend entirely on the logical properties of the propositions which are expressed in the premises of the task. Variations of the wording in which logically equivalent propositions are expressed ought not to change the difficulty of the task. Superior performance on the logically equivalent disjunctive selection task suggests that the conditional selection task is not logically difficult in this sense.

The matching hypothesis, by contrast, can be seen to be more consistent with Johnson-Laird's semantic model of reasoning since it can be regarded as a response to the search for meaning and relevance in the premises of a problem. Errors can therefore be regarded as being the result of relevance judgements which are cued by pragmatic features of the problem. According to this view, the real nature of the difficulty would

seem to lie in the processing involved in forming an adequate representation of the conditional which could lead to a clear identification of a counterexample. This would explain why performance is also greatly facilitated when the problem is expressed in a realistic manner which allows a sensible interpretaton or the counterexample itself to be retrieved from long-term memory.

It has been suggested that realistic versions of the task cue the use of a frame which facilitates the formation of an adequate representation of the problem and the derivation of an appropriate response based on that representation. In abstract versions of the task, errors may occur because there is insufficient contextual information to cue an appropriate frame. In the absence of such contextual information errors may occur, not as a result of logical difficulty, but because the task may be inadequately represented on the basis of pragmatically-based relevance judgements. This possibility will be investigated in the research to be reported here by the use, in addition to the selection task, of other tasks which do not involve conditionals and, while containing misleading pragmatic cues, can also be shown to have minimal logical difficulty.

CHAPTER 2

THE SOURCE OF BIAS IN WASON'S SELECTION TASK

Experiment 1

INTRODUCTION

As mentioned in Chapter 1, one of the most important and well documented findings of research using the selection task is that the nature of its content has a considerable influence on people's ability to solve it. Very familiar and plausible content can produce considerable facilitation in the selection task. On the one hand this may be an all or nothing effect, in the sense that only very plausible versions of the task using familiar relations between the content items have any effect on performance. On the other hand, it may be that the level of insight into, and performance on, the problem may be proportional to the realism of its content. Reich and Ruth (1982) observed a preponderance of matching responses on a less thematic version of the selection task, and a preponderance of what appeared to be verification responses on a more thematic version. They suggested that less thematic versions of the task tend to elicit 'primitive' matching responses, while more coherent thematic content elicits more insightful verification strategies. In common with the great majority of recent studies using thematic material in the context of arbitrary and unfamiliar conditional relations, they found little evidence of a further level of insight to the extent of fully insightful falsification.

In Chapter 1 it was noted that several authors have suggested that

matching bias may be a result of subjects' lack of an alternative strategy on logically difficult problems (Johnson-Laird and Wason, 1977; Manktelow and Evans, 1979; Yachanin and Tweney, 1982). Evans's alternative view of matching as a linguistic bias was also outlined, and it was suggested that the difficulty of the task may be a result of the linguistic properties of certain relational expressions. Reich and Ruth (1982) attribute matching bias to the abstract nature of problem content rather than to its logical difficulty. Their aim is, however, to distinguish between the conditions in which matching rather than verification occurs, and they have little to say concerning why responses are made on the basis of one or other of these biases.

It is not clear why abstract problem content should cause the abandonment of any form of hypothesis testing, so that verification is replaced by matching. However, Reich and Ruth's results require an alternative explanation if this suggestion is to be rejected. The explanation which will be proposed here is based on an idea which has been aired fairly recently in the literature, the implications of which have not been extensively explored.

Yachanin and Tweney (1982) and Griggs and Cox (1983) have suggested that when content items are binary, for example "If there is not a vowel on one side of a card, then there is not an even number on the other side", subjects will tend to recode the negated items into a positive form. Hence "not a vowel" may be recoded to "a consonant", and "not an even number" to "an odd number". This suggested tendency to convert negated items to positive ones depends, according to these authors, on the naturally binary status of the content items. However, this may not be the only factor which can lead subjects to perceive content items as binary. In an appropriate context seemingly non-recodable content items may become recodable. For example, the previously mentioned formulation

'If there is not a B on one side of a card, then there is not a 3 on the other side', although apparently non-recodable, may become recodable in the following circumstances. The task may be formulated in such a way that only two antecedent terms and two consequent terms are mentioned in the problem instructions, either explicitly or implicitly, and only these items appear on the sets of cards presented to subjects. In such contexts there may be a tendency to substitute the remaining positive term for a negated one. Hence given the conditional 'If there is not a 'B' on one side of a card, then there is not a '3' on the other side', where only 'B', 'C', '3' and '4' are shown on the four cards and mentioned in the problem instructions, subjects may tend to convert the sentence to 'If there is a 'C' on one side of a card, then there is a '4' on the other side'. If, on the other hand, subjects are explicitly told in the preliminary instructions that there are four possible antecedent items and four possible consequent items, as in Manktelow and Evans (1979), this tendency may be largely eliminated.

It is also possible that in addition to naturally binary items there are naturally multiple ones. This seems intuitively less obvious, and it may depend either on subjects' experience with a number of alternatives to a denied choice or on the difference in kind between possible antecedents and consequents, so that an alternative item is not readily regarded as a substitute for a negated item. For example, the content in Manktelow and Evans's (1979) problem, items of food and drink, may be naturally multiple in one of these ways. Subjects may be more familiar with situations in which choices between items of food involve more than two possibilities, and the items of food have only edibility in common and are otherwise of different kinds which may not be regarded as appropriately substitutable for one another. Hence, confronted with the sentence "If I do not eat haddock, then I drink gin", subjects may be unlikely to substitute "macaroni" for "not haddock" even if the choice were between only these

two items. This may be because subjects are accustomed to a wider choice of food items, or because the items are of such different kinds; denied the choice of haddock and chips, for example, one would be unlikely to select macaroni and chips as an alternative. Hence the effect of telling subjects in advance that there are four items of food and four items of drink to be considered may be reinforced by the naturally multiple nature of the problem content items.

It will be recalled that the verification hypothesis assumes that subjects take negation into account and the matching hypothesis assumes that they do not. Hence the conversion of negated items into their positive alternatives would make a difference to responses only if selections are made on the basis of a matching strategy. Given that subjects may convert negated binary items to the positive alternative, the matching hypothesis predicts that the positive item would then be regarded as the topic of the conditional sentence and judged to be relevant. Hence subjects may select the cards referred to when negation is taken into account, dismissing the other cards as irrelevant. Yachanin and Tweney (1982) refer to this possibility as "higher-order matching" and in what follows the form of matching previously described will be termed "first-order matching".

A further possible effect of multiple content is that subjects may be more likely to select a named card because of the lack of a salient alternative. This would be so whether or not the item was negated. Where an item is mentioned positively, and there are three possible alternatives, subjects may see little point in testing just the alternative presented in the four-card array. This alternative may be judged to be irrelevant since without also testing the other two possible alternatives nothing would appear to be settled. Attentional factors may also operate against the selection of more vaguely defined multiple

alternatives. With binary content the alternative selection is clearly defined and therefore more likely to be judged to be relevant and to have attention specifically directed to it. Following the considerations of availability discussed by Pollard (1982), the probability of the selection of the unmentioned card would be greater when it is the only possible alternative selection. Hence multiple content may be expected to produce more first-order matching selections on all variants of the problem.

The higher-order matching hypothesis predicts the same responses as verification bias on negated items, but unlike the verification hypothesis it does not apply where selections are made in response to positively mentioned items. In these latter cases first-order matching is the only possible matching response. Hence, higher-order matching predicts that if both an antecedent card and a consequent card are selected in response to a conditional which contains a negated item, the cards selected will be the TA and TC cards. If, due to directional bias, only an antecedent card is selected in response to a conditional in which the antecedent is negated, the selected card will be the TA card. Hence where negation is involved, higher-order matching makes the same predictions as the verification hypothesis: selection of TA alone or of TA and TC. Where negation is not involved, first-order matching bias would also result in the same selections as verification bias. Hence this extended theory of matching bias can provide an alternative explanation for all the selections attributed to verification bias. If these selections are in fact due to two types of matching then the proportion of responses attributable to each of them should be influenced by the extent to which the content of the problem is perceived as binary and recodable.

As previously noted, Reich and Ruth (1982) attributed differences in subjects' selections to the degree of thematicity in the two different versions of the task used. They concluded; "Matching is only in evidence

when the stimulus material is low in thematic content (Expt 1), and is replaced by verification when the stimulus material is high in thematic content (Expt 2)". The less thematic problems (Experiment 1) of Reich and Ruth (1982) contained overtly multiple content items. By contrast, their more thematic problems (Experiment 2) contained some naturally binary content items. Furthermore, in all of these more thematic problems only two antecedent and consequent items were mentioned which, as argued above, would tend to favour perception of the content items as being binary. Hence in these experiments high thematicity was confounded with binary content and low thematicity with multiple content. Reich and Ruth took their results to show the occurrence of more first-order matching with low thematic content. An equally valid interpretation of their results is that they show the occurrence of more first-order matching with multiple content items; a result in accordance with the extended matching hypothesis proposed above.

Accordingly, the present experiment was designed to investigate the effect of high or low thematicity, and of binary or multiple content items, on performance in the selection task. A version of one of Reich and Ruth's (1982) high thematicity (Experiment 2) problems was used in the high thematicity conditions of the present experiment. Reich and Ruth's wording of this problem was as follows:

"Rick is spending his summer holidays fruit picking. The farmer he is working for is very keen that only ripe fruit should be picked to prevent wastage. He tells Rick to judge the ripeness by the colour."

Since 'ripeness' suggests a binary interpretation, 'not ripe' suggesting 'unripe' or a synonym, the version of the problem used in the present experiment (in both the thematic binary and thematic multiple problems) was as follows:

"Rick is spending his summer holidays fruit picking. The farmer he is working for is very keen that only fruit in perfect condition should be picked, to prevent wastage. He tells Rick to judge the condition by the colour."

In the binary version of this problem used in the present experiment subjects were presented with the four variants of the problem including negation, and only two conditions of the fruit ("ripe" and "hard") and colours ("red" and "yellow") were mentioned in the problem instructions and on the cards. The four conditional sentences were worded as in Reich and Ruth (1982); "When the fruit are yellow they are ripe" and its three negated variants. In the multiple condition the colours mentioned were selected from four possibilities ("yellow", "red", "purple" and "green"); and there were four possible conditions of the fruit ("sweet", "rotten", "hard" and "ripe").

The abstract binary problem included the conditional sentence "If there is a 'B' on one side of a card, then there is a '3' on the other side" and its three negated variants. The instructions explicitly stated that only 'B', 'C', '3' and '4' could appear on the cards, and only these symbols appeared on the cards associated with each of the four variants of the problem. In the abstract multiple problem the instructions merely stated that each card had a letter on one side and a number on the other. The set of cards illustrated in the instructions, and the set for each variant of the problem, contained different letters and numbers.

The aim of the experiment was to investigate whether abstract or thematic versions of the task have any effect on response patterns, or whether the differences observed by Reich and Ruth (1982) were due to the binary or multiple nature of the content items. The extended matching

hypothesis predicts that on problems with binary rather than multiple content items, subjects will be more likely to attend to and select cards which are not mentioned in the conditional sentence. Hence their responses to binary problems will be characterized by:

a) More 'TA, TC' and 'TA only' responses to negated items.

b) Fewer 'p,q' and 'p only' selections.

According to Reich and Ruth (1982) the differences in responses will occur between the thematic and abstract problems; with the thematic problems being associated with the two differences, a and b, described above.

The verification hypothesis can also be construed as a rival explanation of first-order matching responses. So construed, all selections of 'TA, TC' and 'TA alone' can be included as 'verification responses'.

METHOD

Subjects

Thirty part-time students participated in the experiment. The majority were attending classes in 'A'-level psychology at Cauldon College of Further Education, Stoke-on-Trent. The remainder were Open University students attending a summer school at Keele University.

Materials

Three different printed instruction sheets were used, relating to: (1) the abstract binary problem; (2) the abstract multiple problem and (3) both versions of the thematic problem. These were as described in Appendix A. To each instruction sheet was attached a four page booklet with a variant of the problem on each page, with four rectangles representing the four cards from which the selection was to be made.

The wording of the sentences associated with each variant of the task is shown below, with the symbols shown on the four cards in parentheses.

Abstract binary problem :

(A) If there is a 'B' on one side of a card, then there is a '3' on the other side. (B,C,3,4)

(B) If there is a 'B' on one side of a card, then there is not a '3' on the other side. (B,C,3,4)

(C) If there is not a 'B' on one side of a card, then there is a '3' on the other side. (B,C,3,4)

(D) If there is not a 'B' on one side of a card, then there is not a '3' on the other side. (B,C,3,4)

Abstract multiple problem :

(A) If there is a 'B' on one side of a card, then there is a '3' on the other side. (B,K,3,6)

(B) If there is an '1' on one side of a card, then there is not a '2' on the other side. (L,R,2,9)

(C) If there is not an 'H' on one side of a card, then there is a '6' on the other side. (H,T,6,4)

(D) If there is not a 'W' on one side of a card, then there is not an '8' on the other side. (W,F,8,5)

Thematic binary problem :

(A) When the fruit are yellow they are ripe. (yellow, red, ripe, hard)

(B) When the fruit are yellow they are not ripe. (yellow, red, ripe, hard)

(C) When the fruit are not yellow they are ripe. (yellow, red, ripe, hard)

(D) When the fruit are not yellow they are not ripe. (yellow, red, ripe, hard)

Thematic multiple problem :

(A) When the fruit are yellow they are sweet. (yellow, purple, sweet, hard)

(B) When the fruit are red they are not rotten. (red, green, rotten, ripe)

(C) When the fruit are not purple they are hard. (purple, red, hard, rotten)

(D) When the fruit are not green they are not ripe. (green, yellow, ripe, hard)

Design

Half the subjects (15) did the abstract binary and thematic multiple problems. The other 15 subjects did the abstract multiple and thematic binary problems. The order of presentation of versions of the problem, and of the four variants of each version was counterbalanced. Hence each subject attempted 4 variants of the abstract problem and four variants of the thematic problem.

There were four experimental hypotheses, which follow from the assumption that differences in responses will be due to the effect of binary or multiple content on the kind of matching bias rather than the effect of thematicity on biases.

1) No difference in the frequency of matching biases between the abstract and thematic conditions.

2) No difference in the frequency of verification bias in the abstract and thematic conditions.

3) More first-order matching with multiple content items.

4) More higher-order matching with binary content items.

Procedure

The subjects participated as two groups of 12; the remaining 6 participating individually. Each was presented with two instruction sheets with accompanying four-page booklets containing the problems. They were told that they were being given two sets of four problems to solve, each set having an associated instruction sheet. They were asked to attempt the problems in the order in which they were presented.

After completion of the experiment, subjects being allowed as much time as they required, they were asked to indicate whether they had previously encounterd the four-card problem concerned. All subjects said that they had not.

RESULTS AND DISCUSSION.

The verification hypothesis and the extended matching hypothesis make specific predictions when a single antecedent card, or one antecedent and one consequent card are selected. The forms of matching to which selections are attributable are indicated on Table 1.1. First-order matching predicts the selection of p alone or p & q on all four variants. Higher-order matching predicts the selection of -p when the antecedent is -p, and 'TA,TC' on the three negated variants (see page 42).

The verification hypothesis construed as a rival explanation of

performance on the task predicts all 'TA, TC' and 'TA only' selections.

TABLE 1.1

Frequencies with which subjects chose all possible card combinations for each variant of each problem.

Card Combination	Abstract Binary				Thematic Binary				Abstract Multiple				Thematic Multiple			
	pq	p-q	-pq	-p-q	pq	p-q	-pq	-p-q	pq	p-q	-pq	-p-q	pq	p-q	-pq	-p-q
TA only	4	5	1	2	2	3	2	2	6	8	0	2	3	2	2	1
FA only	0	0	1	0	0	0	1	0	0	0	0	0	0	0	3	1
TC only	0	0	1	0	1	0	1	0	0	0	3	0	1	0	1	0
FC only	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2
TA,FA	0	0	0	0	1	2	1	1	0	0	0	0	2	2	0	0
TA,TC	7	4	7	6	8	7	7	5	6	1	6	6	8	4	4	4
TA,FC !	0	2	3	2	1	0	1	0	0	4	3	0	0	5	0	3
FA,TC	1	0	0	1	0	0	0	1	0	0	0	0	1	0	4	0
FA,FC	0	1	0	1	0	1	2	2	1	0	0	1	0	0	0	3
TC,FC	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1
TA,FA,TC	1	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0
TA,FA,FC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TA,TC,FC	1	1	2	1	1	0	0	1	0	0	2	2	0	0	0	0
FA,TC,FC	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
All cards	1	1	0	2	0	0	0	1	0	0	0	3	0	0	0	0
No cards	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	0

! = Correct selection
* = Predicted selection for first-order matching.
\+ = Predicted selection for higher-order matching.

In this, and subsequent similar tables, these latter symbols appear above and to the right of the number to which they refer.

TABLE 1.2

Numbers of selections consistent with first-order and higher-order matching and verification for each problem.

	Abstract Binary	Thematic Binary	Abstract Multiple	Thematic Multiple
First-order matching	20	16	25	29
Higher-order matching	20	23	15	15
Verification	36	36	35	28

Table 1.2 summarizes the data in Table 1.1 in terms of the numbers of responses attributable to matching and verification on the four versions of the problem. Table 1.3 groups the data for the abstract and thematic problems.

Table 1.3

Types of selection on the abstract and thematic problems.

	Abstract	Thematic
First-order matching	45	45
Higher-order matching	35	38
Verification	71	64

The differences between the numbers of matching responses to the abstract and thematic problems are clearly minimal, and are not significant. Hence hypothesis 1 is supported. Contrary to the findings of Reich and Ruth (1972) there were fewer verification responses on the thematic problems (64) than on the abstract ones (71). A two-tailed Wilcoxon test indicates that the difference is not significant, as predicted by hypothesis 2. The data from the two abstract and two thematic problems were therefore combined for further comparison.

The top row of Table 1.4 below summarizes the data shown in Table 1.2 as percentages of total responses in order to facilitate comparison with

two other studies which included binary and multiple content items. Comparing the binary and multiple versions in the present experiment, there were significantly more first-order matching responses on the multiple problems ($p < 0.01$, one-tailed Wilcoxon) and significantly more higher-order matching responses on the binary problems ($p < 0.05$, one-tailed Wilcoxon) in accordance with hypotheses 3 and 4. The combined tendency to reduced first-order matching and increased higher-order matching on the binary versions is highly significant (one-tailed Wilcoxon, $p < 0.002$). Only 4 of the 30 subjects showed an opposite tendency, and 18 showed differences in the predicted direction.

Of the 24 correct 'TA,FC' selections shown in Table 1.1, 11 occurred on the 'If p, then not-q' variant, where the correct response is 'p,q'. These responses are therefore more plausibly attributable to first-order matching than to a logical response strategy.

The difference in verification, binary 71 and multiple 64, falls well short of significance; as it also does between the abstract and thematic conditions (see above) in accordance with hypothesis 2. The results of the present experiment are firmly against the hypothesis that thematicity elicits verification responses since there were, in fact, 7 fewer responses to the thematic problems which could be attributed to verification. This result also casts doubt on whether any of the observed responses are due to verification, since the effect of multiple and binary content on responses suggests that they are largely a result of matching. Since, in the light of the present result it seems unlikely that responses are influenced by thematic content in any consistent manner, the results of Reich and Ruth (1982) may be usefully reanalyzed in terms of the multiple or binary nature of the problems in their study.

The results of Griggs and Cox (1983) are also relevant to the

question of the existence of a verification strategy. In their Experiment 1 they compared performance on an abstract selection task using numbers and letters as content with performance on the Sears problem. In their Experiment 2 they used a similar abstract problem which referred to consonants and even numbers. This changes the content from multiple to binary, since 'not a consonant' can be converted or recoded to 'a vowel' and 'not an even number' can be recoded to 'an odd number'. This change was made in order to make the problem more comparable with the Sears problem, which also has recodable (binary) content.

TABLE 1.4

Frequency of three types of response on binary and multiple content problems, as a percentage of all responses observed in each of three experiments.

BINARY PROBLEMS

	First-order Matching	Higher-order Matching	Verification
Experiment 1	30	36	60
Reich & Ruth	29	37	58
Griggs & Cox	20	25	35

MULTIPLE PROBLEMS

	First-order Matching	Higher-order Matching	Verification
Experiment 1	45	25	53
Reich & Ruth	43	6	24
Griggs & Cox	38	14	29

In Table 1.4 the relevant features of the results of Reich and Ruth (1982) and Griggs and Cox (1983) are presented in the same way as the

results of the present experiment. The figures are shown as percentages, for comparison. There appears to be a remarkably consistent effect for binary content. In each case there is a small but consistent predominance of higher-order matching. With multiple content, first-order matching bias is consistently more in evidence, at similar levels in all three studies; while higher-order matching, although consistently less in the multiple condition, varies considerably between the three studies. The very low figure (6) in Reich and Ruth's Experiment 1 may reflect the naturally multiple nature of the content items as discussed in Chapter 1. These items of food and drink are known to elicit a high proportion of first-order matching responses from the results of Manktelow and Evans (1979, Experiment 2), of which Reich and Ruth's Experiment 1 was a replication. The negation of one of them may not readily suggest its positive substitution by the alternative item in the array of cards.

An alternative way of looking at the data is to observe the extent to which the basis of responding differs between the binary and multiple conditions. This provides a measure of the extent to which the basis of subjects' responding has changed between the binary and multiple conditions. In the Griggs and Cox study these differences are very similar to the differences observed in the present experiment. Griggs and Cox did not include single antecedent card selections in the predictions of first-order matching bias and, as a result, failed to recognize the magnitude of the difference resulting from multiple or binary content. In any event, this comparison was not envisaged by their experimental design. Their omission of single antecedent card selections is justifiable only in the sense that it does not follow from considerations of matching bias alone. However, a linguistic explanation of such choices in terms of a directional bias, due to greater apparent relevance of the antecedent, was discussed in Chapter 1. It was argued that such choices should be included in the predictions of the matching hypothesis, just as the

verification hypothesis is taken to predict single antecedent card choices arising from a tendency to make a conditional rather than biconditional interpretation of the conditional sentence in the task.

The data of Reich and Ruth also show a difference in the frequency of first-order matching with the two types of content. This difference is similar to that observed in the present experiment, and the absolute figures are also very similar. The considerable reduction in higher-order matching on their multiple problem (Reich and Ruth, 1982; Experiment 1) was not observed in the present study, and an explanation for this has been offered above in terms of the degree of emphasis placed on the existence of the four possible food or drink items, and also their possible 'naturally multiple' status. The considerable reduction in higher-order matching may be a result of subjects' greater awareness of the existence of multiple alternatives. This could have deterred them from converting a negated item to the positive alternative presented in the array of four cards, since the other alternatives may well have remained salient. The minimal tendency towards higher-order matching is partially reflected in the greater incidence of first-order matching on this multiple problem; but for some subjects first-order matching tended to occur only in the choice of a consequent card. This aspect of the data will be discussed in detail in the context of Experiment 6 (Chapter 5). Despite some variation in the absolute incidence of the responses described (which are not unexpected in view of the widely differing formulations of the problems concerned), the consistency of the change in responses associated with the inclusion of binary or multiple content items on forms of matching bias suggests that the effect is reliable.

There may also appear to be evidence of a higher incidence of verification responses where binary content is included. Since all

higher-order matching responses are also classifiable as verification responses, a sufficiently large change in the incidence of the former will produce a significant change in the latter. This is what seems to have occurred in Reich and Ruth's experiments. In the case of their binary problem the effect is increased by the existence of 6 'p only' selections on the 'If p, then not-q' variant (which count as verification responses, but as first-order rather than higher-order matching) compared with only 3 such responses to the equivalent multiple problem. This variation in number of selections of an antecedent card only is small enough to be explained by the very different context of the problems concerned.

Since the effect of binary content is predicted by the extended matching hypothesis, but not by the verification hypothesis, the falsity of the latter hypothesis is strongly suggested. At the same time an alternative explanation has been offered for the responses which have been attributed to verification bias, and evidence from two other studies has been shown to support the suggested explanation.

The fact that results such as those observed in Reich and Ruth's Experiment 2 can occur in some (binary) versions of the selection task has not previously been given a detailed alternative explanation to that offered by the verification hypothesis. The existence of such data could therefore have led to the continued acceptance of the verification hypotheses by some experimenters. Higher-order matching offers an alternative explanation of any selection task experiment (past or future) which includes content items which can be perceived as binary in any of the ways described above. For example, the results of Yachanin and Tweney (1982) were described in Chapter 1 as showing evidence for both matching and verification. These authors were, however, the first to offer higher-order matching as an alternative explanation of the 'verification responses' observed. In the light of the present results it seems that

their suggested explanation is probably the correct one. Yachanin and Tweney used content items which were binary, but did not emphasize the fact to subjects. On the basis of the present results with binary problems, and those of Griggs and Cox (1983) and Reich and Ruth (1982), one would expect to observe responses based (at approximately equal levels) on both types of matching responses. Hence proponents of the doctrine of mental logic are no longer in a position to cite such studies as empirical support for the existence of a verification bias. Such a bias, if it existed, could only be implemented by a logic in the mind with the ability to pick out items which instantiate the truth of the antecedent and consequent of the conditional sentence.

The occurrence of higher-order matching in Experiment 1 suggests that the conversion of negated binary items is carried out by means of direct, truth-functional inferences of the kind described in Chapter 1. In this case the premise 'The letter is B or C' stated or implied in the task instructions, and the antecedent of the conditional 'The letter is not B', permit semantic composition to derive 'False or the letter is C'. Knowledge of the semantics of 'or' allows the conclusion 'The letter is C' to be derived by direct inference. Where there are four possible antecedent symbols, the premise implied by the task instructions would be of the form 'The letter is B or C or D or E'. Semantic composition with the antecedent 'The letter is not B' yields 'False or the letter is C or D or E'; from which follows 'The letter is C or D or E'. Hence no useful direct inference can be made in this case, unless only the two letters on the cards in the currently presented array are considered by the subject.

It appears that subjects sometimes do consider only the items in the currently presented array, and higher-order matching is therefore reduced but not entirely eliminated by multiple content items. Such an effect is only possible when two antecedent and two consequent cards are displayed

as in the standard selection task. Hence a display consisting of three antecedent and three consequent cards might be tried in a future experiment in order to ascertain whether higher-order matching would be completely eliminated under those conditions.

CHAPTER 3

Experimental evidence for the occurrence of direct inferences has been presented from two sources: the disjunctive selection task (Wason and Johnson-Laird, 1979) and the observed occurrence of higher-order matching on the conditional selection tasks in the experiments discussed in Chapter 2. The inference involved in converting a negated item to its positive alternative has been shown to be followed by few correct solutions in the selection task. It does not therefore occur as part of a logical strategy, but generates the responses which have been attributed to higher-order matching, none of which is the correct response. Hence these inferences are psychologically different from the processes underlying correct solution of syllogisms and other problems, where a valid reasoning strategy is implicated and there is no direct inference route to the solution. The existing evidence does not indicate whether the negated items are converted to positive ones prior to making the relevance judgement responsible for the matching response, or subsequently in such a way as to revise a relevance judgement which has already been made. The latter alternative seems more probable since the topic of the sentence would need to have been decided, at least provisionally, before it would be apparent what items were sufficiently relevant to merit conversion to positive form. In either case this conversion process appears to be part of the process of forming a representation of the problem's premises.

It has been argued that where, because of the linguistic complexity of the premises, direct inferences are not cued (perhaps because similar complex situations are rarely encountered, and no appropriate frame has developed) subjects respond on the basis of a relevance judgement. It was

also argued in Chapter 1 that the logical difficulty of the problem is not a factor in determining the basis on which the response is made. As evidence for this view, it was noted that a variant of the conditional selection task using wording of the form 'If not-p, then q' tends to elicit few correct responses. Yet 'If not-p, then q' is logically equivalent to the 'p or q' sentence (interpreted as exclusive disjunction) used in the disjunctive selection task; and this latter task elicits a high proportion of correct responses. It is therefore the linguistic complexity of the former task which gives rise to its difficulty. Subjects do not attempt the logical task because the conditional wording is too complex to reveal what that task is. They therefore do not become aware of any logical difficulty for two reasons; they do not understand the logical structure of the problem and, if they were to do so, the logical structure is the same as that of the 'p or q' problem which is easily solved.

A potential problem in arguing as above is that all the evidence for the suggested conclusion has been derived from studies using a problem (the conditional selection task) which, despite the above objections, is frequently judged to be logically difficult by proponents of the cognitive short-circuiting hypothesis. Clearly they must insist on this point in order to argue that it is the logical difficulty of the conditional selection task, rather than its linguistic complexity, which gives rise to matching.

Proponents of the doctrine of mentallogic might follow up this insistence by arguing that all reasoning is truth-functional, and the difficulty of making direct inferences about conditionals is simply a difficulty of reasoning in this way, rather than one of comprehension. This argument, however, leaves no room for explanation of the observed differences in performance. If all reasoning were truth-functional, then

reasoning about 'p or q' (understood as exclusive disjunction) and 'If not-p, then q' would be of equal difficulty since their truth-tables are identical. They assert the same proposition in different ways, and therefore have identical logical properties. Differences in performance on problems using these formulations must therefore be due to difficulties in comprehending the conditional wording. If both were comprehended correctly, the remaining logical task would be the same in both cases.

Alternatively, it could be argued that no reasoning is truth-functional; that humans reason only by the construction and evaluation of mental models. This could not, of itself, explain the difference in performance with 'p or q' and 'If not-p, then q', because a complete and accurate set of mental models of each of these premises would be identical in their logical properties. The difference would again have to lie in the greater difficulty of forming an accurate representation of the conditional premise, even though it would be identical to the representation of the disjunctive premise. This would amount to saying that the difficulty lies in appreciating the complete set of truth-conditions of the conditionaland hence of going from a propositional representation of it to one which reveals its logical structure. Again, the difficulty must arise at a stage in the processing before the logical structure of the problem has become apparent. It is therefore misleading to call it a 'logical difficulty' rather than a linguistic one, since no theory of logical reasoning is capable of distinguishing between two linguistic structures with identical logical properties and abstract content.

A third possibility is that the difference in responses to conditional and disjunctive formulations is to be explained in terms of the pragmatic implications of these forms. Conditional formulations may imply that the antecedent and consequent are relevant to each other in a

way which is to be made apparent by their content and context. Hence comprehension of context-free conditionals with abstract or arbitrary content is difficult. Comprehension of disjunctives, at least those which do not include negation, may be less dependent on content and contextual factors. Disjunctions, unlike conditionals, may imply a lack of mutual relevance between the content items rather than the existence of such relevance. There is therefore no need for further information in order to elucidate the nature of the disjunctive relation prior to forming an adequate representation of it.

One way of circumventing these alternative interpretations of the evidence obtained from the selection task research is to use different problems in order to test the cognitive short-circuiting hypothesis. The three experiments which follow adopt this approach. In Experiments 2 and 3 the element of 'logical difficulty' is intentionally minimized in order to investigate whether responses continue to be made on the basis of a pragmatically-based heuristic strategy. Experiment 4 was designed to investigate the extent to which subjects comprehend sentences on the basis of their syntactic form. If the influence of syntax on perceived meaning proves to be minimal when pragmatic cues are present, then it would follow that such cues would forestall comprehension of the logical structure of the sentence, which is primarily conveyed by its syntactic structure. Hence a pragmatically-based response, would be attributable at most to difficulty of comprehension, and not to difficulty of logical processing once that comprehension has been achieved. Subjects' own evaluation of the difficulty of the sentences concerned will be included in the results of Experiment 4, in order to decide whether difficulty of comprehesion is a factor in pragmatic processing, or whether subjects automatically comprehend on the basis of pragmatic cues without attempting to use, and therefore without becoming aware of difficult syntactic structure.

To return to the purposes of Experiments 2 and 3, an empirical test of the cognitive short-circuiting hypothesis would involve observing what occurs when a logical problem is demonstrably of only moderate difficulty, because subjects respond to it correctly for logically valid reasons. Other subjects could then be given a task which could be completed either by solving the original logical problem or by making a relevance judgement. If subjects were to respond on the basis of a relevance judgement, it could not then be argued that they did so because the logical route to the solution was too difficult.

In Experiment 2, a problem which requires some logical reasoning is presented to subjects in order to determine how difficult it is. The measure of difficulty adopted is the proportion of subjects who fail to show complete insight into the problem. This procedure was carried out as a separate experiment since, if very few or no subjects showed insight into the problem, there would be no point in conducting Experiment 3 using the same problem. However, given a reasonable level of insight into the problem in Experiment 2, it is to be used again in Experiment 3 in order to determine whether subjects tend to respond on the basis of formal reasoning of which they should be capable, or to base their responses on relevance judgements.

Experiment 2

The first of the two experiments outlined above was designed to establish a base level of performance on a logico-mathematical problem. The problem was described to subjects as follows:

"All the leaves fell from a tree in 10 days. On each of those days 100 more leaves fell from it than fell on the previous day. How many leaves fell on the second day?"

Subjects were asked to attempt the problem and to write down their solution and the steps used in their arrival at the solution. They were also asked to write down the number of days they had to consider.

The correct solution to this problem is arrived at by appreciating that the first sentence entails that no leaves fell on the day before the first day (day 0). Hence, since 100 more leaves fell on day 1 than day 0, as entailed by the description of the problem, 100 leaves must have fallen on day 1, and hence 200 leaves on day 2. Hence it would be necessary to consider 3 days: day 0, day 1 and day 2.

Subjects who answered correctly with "200 leaves" and showed their working as "0 +100 +100 = 200" and said that they had to consider 3 days were deemed to have total insight into the problem. Subjects who answered correctly with "200 leaves" but showed their working as "100+100 = 200" and said that they had to consider only 2 days were deemed to have answered through guessing, and therefore not to have insight into the problem. Failure to respond was similarly classified.

METHOD

Subjects

The subjects in the experiment were 20 students at Keele University who participated individually.

Materials and Procedure

Subjects were presented with printed sheets containing the problem and questions described above and allowed as long as they required to respond.

RESULTS

Of the 20 subjects 7 showed total insight into the problem as described in the introduction. Another 3 gave the correct answer but possibly on the basis of guesswork, since they responded that they had considered only two days and their working was "100 + 100 = 200". Seven subjects gave answers containing an unknown value "x", all except one of these being "x + 200". The remaining 3 subjects gave no answer. From this result it was concluded that about 35% of subjects in the population sampled could be expected to have total insight into the problem.

Experiment 3

INTRODUCTION

This experiment was designed to investigate what proportion of subjects drawn from the same population as Experiment 2 would reject an apparently relevant but actually contradictory additional premise to the problem used in Experiment 2. The conclusion was to be reached by comparing the proportion of subjects who rejected the additional premise with the proportion who showed total insight into the problem presented alone: 35%. This would indicate the extent to which subjects tend to respond on the basis of a relevance judgement, rather than on the basis of

some deductive reasoning which many of them would be capable of carrying out.

METHOD

Subjects

Twenty students at Keele University participated individually in the experiment.

Materials

Subjects were presented with printed sheets containing the same problem as in Experiment 2, both in its original form and with the additional premise "200 leaves fell on the first day".

Design and Procedure

Half of the subjects were presented with a printed sheet which described the original problem first, followed by the version of the problem with the additional premise. The other half of the subjects were presented a printed sheet with these versions of the problem in reverse order, in order to control for possible order effects. All were asked to consider both problems and then to state which version of the problem,if any, would allow them to answer it with a definite numerical answer; to answer the question if possible; to show their working and to say how many days they had to consider. Subjects were allowed as long as they required to respond.

RESULTS

All 20 subjects gave the same response. They chose the version of the problem with the additional inconsistent premise, gave their working as "200+100 = 300" and said that they had to consider only two days.

DISCUSSION

Since 7 of the 20 subjects participating in Experiment 2 showed total insight into the original problem, a similar number could be expected to show total insight in the present experiment. However, no such logical insight was demonstrated by the subjects in the present experiment. From this it is concluded that when a relevance judgement is a possible basis for responding to a problem, a response is likely to be made on that basis rather than on the basis of a deductive reasoning strategy. This appears to have occurred in the present experiment in spite of the fact that the required deductive reasoning should have been within the capabilities of a substantial proportion, about 35%, of subjects.

It therefore appears that solutions based on relevance judgements are not always satisficing options in the face of logical difficulty. Instead, it seems that the existence of an alternative basis for responding, by making relevance judgements, can in suitable circumstances determine the way in which a problem is attempted. This can occur even when, as here, some subjects are capable of arriving at a logically correct solution using deductive reasoning.

The relevance judgement concerned in the present experiment is invited by a premise which is separate from the premises of the original problem. This separation was necessary in order to offer subjects the opportunity to reject the apparently relevant premise and to reason on another basis. In this respect the falling leaves problem differs from the selection task where the apparently relevant information is embedded

in the original premises. Nevertheless, the results at least confirm that subjects participating in the selection task could be responding on the basis of a relevance judgement without in any sense becoming aware of the alleged logical difficulty of the task. The theoretical case outlined above appears to be strong enough to put the onus on the cognitive short-circuiting theorists to demonstrate that performance on the selection task is a result of its alleged logical difficulty.

In a recent study Byrne (1986) showed that in an easy conditional reasoning task involving modus ponens inferences additional apparently relevant information made such inferences significantly less frequent. Byrne found that given the premises 'If it is raining then she will get wet', and 'It is raining', most subjects concluded that 'She will get wet'. However, when an additional premise was added to the task: 'If she goes out then she will get wet', significantly fewer subjects drew the conclusion. In Byrne's experiment subjects appeared to be reasoning on the basis of pragmatic considerations and assuming that the additional premise is relevant. Hence reasoning on this basis appears to be a preferrred option even when there is little question of logical difficulty.

Why do subjects appear to abandon modus ponens reasoning under these conditions? One possibility is that they were not using such an inference rule in the first instance. If subjects were making the original inference using mental models, then the pragmatic relevance of the second premise would lead to an extension of the model including the possibility that 'She might not go out'. Hence by continuing to reason on this basis subjects would be unable to reach a firm conclusion. Where the content of a problem is realistic and plausible, subjects are likely to approach the problem pragmatically and to use the more salient information in the construction of mental models.

On more abstract problems subjects may tend to use truth-values rather than the actual content items in representing the premises of the problem. However, this is likely only in the case of problems which allow direct inferences to be made. The results of research using the disjunctive selection task suggest that one of the conditions leading to relevance-based solutions is that, as in the problem used in Experiment 3, there is no direct inference route to the solution. Where such a route exists, as in the disjunctive selection task, subjects are more likely to respond on that basis rather than on the basis of a relevance judgement.

As remarked in Chapter 1, Johnson-Laird and Wason (1977) suggested that "Matching may be a response peculiar to extreme bafflement, or lack of appreciation of logical structure". It has been demonstrated above with what readiness subject used relevance judgements in responding to the version of the Falling Leaves Problem in the present experiment, a not particularly baffling problem. This suggests that subjects comprehend the task in a way which does not reveal its logical structure. Hence subjects would not be baffled even if a baffling logical structure were involved. Comprehension takes place on the basis of pragmatic relevance judgements which, in the case of the selection task, result in matching responses.

Evidently comprehension of logical structure occurs only when a logical relation is expressed in a simple linguistic form such as 'p or q' or when the logical structure appears in a familiar context. In the latter case it seems that subjects are really comprehending the pragmatic structure of the task which, in the most facilitatory cases, is isomorphic with its logical structure. It seems reasonable to suppose that similar processes are involved in the comprehension of all verbally presented complex problems. Hence, in the case of the selection task, the complicated process of forming an adequate representation of its logical

structure would be a major reason for its difficulty. More accurately, it is not a source of difficulty but a source of error, since the majority of subjects are not cued to form a representation of the logical structure of the problem. Hence they may find it easy to give a response: a matching response.

Experiment 4

INTRODUCTION

In the pursuit of an explanation of subjects' responses in the selection task it has been necessary to explain specific behaviours in terms of the way in which they are determined by more general cognitive processes. First-order matching has been explained in terms of the relevance judgements involved; the relevance judgements being cued by the process of linguistic comprehension. With the unfamiliar and artificial material in the selection task subjects appear to reach solutions by making any direct inferences and relevance judgements which are possible. The results of Experiments 2 and 3 suggest that responses are sometimes made on the basis of relevance judgements rather than on the basis of a logical strategy, even though the use of such a strategy is within the capabilities of the subject.

In order to solve a problem by use of a logical strategy it would be necessary to process its component sentences syntactically in order to determine the logical relations between the items mentioned in the sentences. This suggests that the tendency to comprehend sentences on the basis of the relevance judgements they give rise to, rather than on the basis of their syntactic structure, may be an instance of a more general phenomenon. It may be that sentences tend to be comprehended primarily on the basis of pragmatic factors rather than on the basis of their syntactic structure. In other words, the grammatical structure of the sentence as a whole may not be routinely used in comprehending it. This is analogous and related to the failure to use logical structure in comprehension, since the formal logical structure of a sentence is conveyed by its syntactic structure. It is therefore possible that matching bias is a

result of the primacy of pragmatic processing (not just relevance judgements) in comprehension.

In order to test the hypothesis that comprehension sometimes takes place by use of a pragmatic rather than syntactic processing strategy, a sentence can be used of which pragmatically based processing would yield a different interpretation from syntactically based processing (semantic processing being included as a necessary precursor of pragmatic processing). Such a sentence has been mentioned by Bennett (1976) who remarks that nurses and first-aid trainees are sometimes taught 'No head injury is too trivial to be ignored'. The intended meaning of this sentence is that no head injury is too trivial to receive attention, hence processing which takes the sentence's grammatical structure fully into account would reveal it to say something absurd and contrary to the intended meaning. By contrast, pragmatic processing, being a heuristic process for making sense of a sentence, would yield a plausible interpretation.

If subjects are mainly affected by pragmatic features in their interpretation of this sentence, they could be expected to find it a reasonable one to use in the circumstances. If, on the other hand, subjects understand the sentence by subjecting it to syntactic analysis, then they will appreciate that, formally speaking, it fails to express the intended meaning. Hence the hypothesis can be tested that the relevance judgements which give rise to matching bias are a special case of the pragmatic processing of normal comprehension. Requiring subjects to evaluate the sentence for accuracy and comprehensibility serves as a test of whether subjects understand the sentence with or without passing through a stage at which it seems to them to be baffling. This would indicate whether the sentence is subjected to syntactic processing in the course of comprehending it. Wason and Reich (1979) conducted an experiment

using sentences of this form with differing levels of plausibility Two examples are; 'No missile is too small to be banned' and 'No error is too gross to be overlooked'. In all 8 sentences the adjective 'agreed' with the verb in the sense that it is plausible that the smaller a missile is, the less one might be inclined to ban it. Contrast the sentence 'No head injury is too trivial too be ignored', where it is implausible that the more trivial an injury is, the less one would be inclined to ignore it. All 16 subjects correctly paraphrased two of the sentences, while the smallest number of correct paraphrases of a sentence was three.

Wason and Reich (1979) report that in their experience the 'head injury' sentence is almost invariably misconstrued to mean that no head injury is too trivial to be noticed. The predominance of this plausible interpretation of the sentence suggests that it tends to be understood on the basis of pragmatic considerations. However, it is not clear whether this reflects subjects' initial route to comprehension. They may make an initial attempt to understand it on the basis of its semantic content and syntactic form, and as a result of its complexity fall back on pragmatic cues. In this case subjects could be expected to report that the sentence is badly expressed and difficult to understand. A high rating of the sentence would suggest that subjects initially comprehend it on a pragmatic basis. This would lend support to a view suggested earlier: that matching bias results from an initial tendency to make pragmatically based relevance judgements, rather than from a failed attempt to analyse the logical structure of the selection task.

METHOD

Subjects

Eleven subjects participated on a voluntary basis. All were native speakers of English, and the majority were university students or graduates. Their ages ranged from 11 years to 70 years, and their linguistic experience ranged from that of a schoolboy to that of a professional translator.

Materials

A printed sheet was given to each subject containing the following text:

Understanding Sentences

I am trying to compare readers' understanding of sentences written in different ways.

As a test of this I am taking as an example something a teacher of first-aid might want to say. Suppose that he wants to tell his pupils that they must always take notice of any head injury, however minor. Or, to put it another way, that they must not ignore any head injury.

Some ways of saying this seem better than others. In order to test this I have listed some sentences which might be used. In order to compare a wide range of sentences I have included some which are probably stupid.

Please give each of the following sentences a mark from 0 to 10 depending on how well it will be understood by learners to make the teacher's point about head injuries. If you think the sentence will be understood to mean

the opposite to what is intended, or does not make any sense, or that nobody could be expected to understand it, please give it zero '0' marks. If a sentence is perfectly clear and accurate, so that no mistake could be made, give it 10 marks.

MARK OUT OF 10

1. Always treat any head injury as though it might be serious. ___
2. Never ignore any minor head injury. ___
3. No head injury is serious. ___
4. That a head injury which does not appear to be more than trivial must not be ignored must not be forgotten. ___
5. If someone has a head injury which seems to be trivial, it is still a good idea not to ignore it. ___
6. No head injury is too trivial to be ignored. ___
7. A head injury may seem to be trivial, but it could turn out to be serious, and it should not therefore be ignored. ___
8. Minor head injuries can be serious. ___
9. The more trivial a head injury, the more it requires attention. ___
10. No head injury is too negligible to be neglected. ___

Design and Procedure

Subjects were presented with the printed sheet and asked to complete it with their marks for each of the ten sentences. The main comparison to be made was in the marks given to sentence 6, the target sentence, and sentence 5 which seems to convey what is intended reasonably clearly and contains the same negatively weighted words: 'trivial' and 'ignore'. The other sentences were included to ensure that subjects were giving appropriate marks to difficult sentences such as sentence 4, and zero marks to sentence 3 which is opposite in meaning to that intended. The additional sentences would also serve to make the somewhat misleading guise of the experiment more plausible to subjects.

RESULTS

TABLE 4.1

Marks given to the 10 sentences in ascending order of total marks.

Sentence no.	3	9	4	10	8	5	7	2	1	6
Total marks	0	17	31	72	82	85	91	92	100	102

The target sentence (sentence 6) was given the highest total mark (102) even though other sentences such as 1, 2, 5 and 7 seem to be clear and accurate. This score was significantly higher than that given to sentence 5 (85 marks), ($p < 0.05$, one-tailed Wilcoxon Matched-Pairs Signed-Rank Test), although sentence 5 expresses the intended meaning without containing any anomalous features. It is, however, sufficient for the present purpose that the target sentence (sentence 6) was ranked at least as high as some non-anomalous sentences with the same intended meaning.

In view of the fact that a strict and literal interpretation of

sentence 6 reveals that it has implications which are both absurd and contrary to the intended meaning, it is clear from subjects' high ranking of it that the sentence is understood primarily by pragmatic means rather than syntactically. Furthermore, this was the case in spite of the fact that subjects were asked to evaluate the sentences, which should have engendered a more than usually critical and analytic reading.

Discussion of Experiments 1 to 4

In Chapter 1 a number of questions were raised concerning the reason why subjects frequently make erroneous responses to the selection task. One of these questions concerned the kind of bias which the observed responses reveal. The results of Experiment 1 suggest that the majority of responses result from matching bias of the first or second order, and that there is little evidence of verification bias. A second question concerned the origin of matching bias and whether it is due to the logical difficulty of the task or to the linguistic complexity of its wording. It was argued that in view of the prevalence of correct solutions to a disjunctive version of the task (Wason and Johnson-Laird, 1969) the logical difficulty of the logically equivalent conditional version of the task could not explain the results obtained. Experiments 2 and 3 lend support to this view by showing that heuristically based responses can occur even when a problem involves a logical task of only moderate difficulty.

A further requirement of the 'logical difficulty' explanation of matching is that the selection task be comprehended in a way which reveals its logical structure. Comprehension of this kind requires complete syntactic processing of the relevant sentences. In Experiment 4 it was observed that a linguisically complex sentence was comprehended primarily

on the basis of its pragmatic and semantic properties. Hence, even when there is no logical task to contribute 'logical difficulty', responses may still be made on a basis which discounts the syntactic structure of a sentence. The hypothesis that subjects respond as they do as a result of logical difficulty therefore appears implausible in view of the fact that even when there is no logical problem involved subjects may respond on the basis of semantic and pragmatic information alone.

This leaves linguistic complexity as the most probable explanation of selection task performance. In the next chapter some evidence which seems to contradict this view will be described and evaluated.

In the preceding chapters it has been argued that the difficulty of the selection task is due to the linguistic complexity of its conditional wording. Empirical support for this view has been given by the results of Wason and Johnson-Laird's (1969) disjunctive selection task experiment. Other researchers however, notably Van Duyne (1974) and Legrenzi (1970), have used versions of the task with wording which was not in conditional form and included disjunctive formulations. Van Duyne and Legrenzi did not observe any significant facilitation when these other formulations were used. Their experiments will be described in detail later, but for the moment a common feature of all previous experiments using alternative wording is to be considered. This is the fact that all such wordings have been formulated by the experimenters involved, and may therefore have been difficult for subjects to comprehend. In the next experiment to be described this feature was avoided by using forms of wording which had been previously elicited from the particular subject concerned. This should ensure that the wording is easily comprehensible to the subject, thus ensuring a fairer test of its facilitatory potential. In addition, analysis of subjects' own formulations of the relation concerned might suggest the existence of a form of wording which is preferred by a majority of subjects and could prove to be generally facilitatory.

Experiment 5

INTRODUCTION

This experiment can be regarded as consisting of two distinct halves.

In the first half subjects were presented with a form of truth-table relating to four conditional sentences. These sentences referred to an imaginary card game in which only certain pairings of a letter-bearing card and a number-bearing card are acceptable. The four tables related to the four variants which are possible when negation is included in the conditional sentence "If the letter is 'B', then the number is '3' ".

Subjects were asked to formulate a rule which would inform an imaginary partner in the card game which pairs of cards should be accepted. They were not allowed to mention letters other than 'B' or numbers other than '3', in order to elicit equivalents of the negated forms of the conditional sentence.

In the second part of the experiment subjects were presented with 8 variants of the selection task. Four of these contained the standard wording as quoted above, and its negated variants. The other 4 contained the wording that the subjects had produced in the first part of the experiment. The only difference was that 'B' and '3' were changed to 'V' and '6' respectively, and the items on the pairs of cards changed to 'V', 'W', '6' and '7'. This change was made so that if subjects happened to recall a truth-table associated with one of their formulations it would not be possible to derive the counterexample to their formulation directly from it.

The first part of the experiment was therefore designed to provide evidence regarding the principles which underly verbal formulations of this kind of logical relation by competent language users. It should also show whether any formulation was generally preferred. The second part of the experiment should indicate whether subjects are able to perform better on the selection task when the relation between the content items is described in their own words, and therefore in a way which would be

familiar to them.

METHOD

Subjects

Eighteen undergraduate students of Keele University participated in the experiment on a voluntary basis. Six of them had to be eliminated from consideration. In two cases there was a failure of the equipment or program and a further two subjects felt unable to continue with the second part of the problem, and would have been pressed for time had they done so. The remaining two subjects seemed to miss the point of the first part of the experiment, and entered only letters and numbers. As a consequence they could not respond to the 'own wording' versions of the selection task, and they also produced no correct solutions to the standard selection task.

Materials

The problems were presented using Apple II microcomputers with monitors to display the instructions and problems and disc drives to store responses. Responses were entered using the computer keyboards.

Two printed instruction sheets were also provided which contained the same instructions as those displayed on the monitor screen. The subjects could therefore refer to earlier instructions if they had been forgotten. The exception to this was that the first instruction sheet related to the first part of the experiment, and was replaced by the second instruction sheet when the first part of the experiment had been completed. The text of the instructions is shown in Appendix B. The problems presented to

subjects are described in the main text below.

Procedure

Subjects were tested individually, the procedure being carried out by the computer program. After extensive instruction (described in Appendix B) they were presented in turn, and in randomized order, with the four tables shown below and asked to type in their own words an instruction which would convey to an imaginary partner which pairs of cards were acceptable. They were not allowed to mention 'C' or '4', and were instructed to mention 'B' and '3' as few times as possible. If subjects accidentally mentioned 'C' or '4' the computer gave an audible warning, an error message was displayed on the screen describing the mistake, and the subject was invited to try again. If subjects pressed 'Return' without entering anything, a similar procedure resulted.

The four tables are shown together with the standard conditional wording relating to them. This wording was not, of course, seen by subjects until the second part of the experiment.

B 3 Accept
B 4 Do not accept
C 3 Accept
C 4 Accept

If the letter is 'B', then the number is '3'.

B 3 Do not accept
B 4 Accept
C 3 Accept
C 4 Accept

If the letter is 'B', then the number is not '3'.

B 3 Accept

B 4 Accept

C 3 Accept

C 4 Do not accept

If the letter is not 'B', then the number is '3'.

B 3 Accept

B 4 Accept

C 3 Do not accept

C 4 Accept

If the letter is not 'B', then the number is not '3'.

After more instructions (see Appendix B) subjects were presented with eight selection tasks in randomized order. Four of these were worded as in the conditional sentences associated with the above tables, and four were in the subject's own words as entered in the first part of the experiment, except that in all cases 'B's were changed to 'V's and '3's to '6's. In each case the associated table shown to subjects was as follows:

V *

W *

* 6

* 7

Subjects were told that '*' denotes a face-down card, and were asked to type the symbol on the card paired with any face-down card they would need to turn over in order to decide whether the pair was acceptable according to the associated instruction.

If subjects typed anything other than 'V', 'W', '6', '7' or 'none' they were informed of their error, and invited to try again. Typing '*'

resulted in a message to type the symbol on the card paired with the intended face-down card. The responses were stored on disc with indications as to which variant of the problem they related.

RESULTS AND DISCUSSION

The forms of wording produced by subjects in the first part of the experiment are shown in Table 5.1. Since subjects were free to use any form of words they found appropriate, responses were formulated in various ways. However, a useful first indication of the underlying form of a response was provided by the items which were negated. These negated items differ for each of the three main logically equivalent ways of expressing the relation concerned. For example, the formulations which are logically equivalent to the positive conditional 'If p, then q' (no negation) are 'Not both p and not-q' (q negated) and 'Not-p, or q (p negated). Subjects' formulations, although sometimes idiosyncratically expressed, tended to confirm the structure initially suggested by the position of these negations. There was only one response (see paragraph preceding Table 5.2) which could not be interpreted as being a logical equivalent of the relevant conditional.

Table 5.1

Numbers of instances of the forms of wording used in Experiment 5

Conditional Equivalent	p -> q	p -> -q	-p -> q	-p -> -q	Total
General form of subjects' wording	Specific form (where different) next to number				
p only if q	2	p OI -q 0	-p OI q 0	q OI p 2	4
-(p & -q)	6	-(p&q) 11	-(-p&-q) 4	-(-p&q) 8	29
-p v q	3	-p v -q 1	p v q 7	p v -q 0	11
Others	0	0	0	p v (-p&q) 1	1
Unclassifiable	1	0	1	1	3

Examples of subjects' wording, on which this table is based, are given in Appendix C.

Twenty-nine (60%) of the responses could be classified as having the form 'Not both p and not-q'. This is a formulation which immediately calls attention to the counterexample to the problem, 'p and not-q', and higher-order matching responses to 'p' and 'not-q' would produce the correct solution as a result of a relevance judgement alone. The most frequently obseved variant of this formulation was the one with minimal negation '-(p & q)' which constituted 11 (38%) of the instances. The most highly negated variant '-(-p & -q)' was least frequent with 4 (14%) of the instances.

The next most frequent formulation (23%) was 'Not-p or q'. A disjunctive form of the selection task with the wording, "Every card has a square which is black on one side, or a line which is crooked on the other side" was used in Wason and Johnson-Laird's (1969) experiment which has previously been discussed. It will be recalled that it elicited corrects solutions in 75% of cases. The additional negation (not-p) in the formulation 'not-p or q', compared with 'p or q' increases its difficulty. However, this generalized representation of the wording is slightly misleading since seven (64%) of the eleven disjunctive formulations were in response to the 'If not-p, then q' table, where no negating term is required because the disjunctive form is, in fact, 'p or q' (see Table 5.1).

Conditional formulations were uncommon. There were 4 (8%) formulations using an 'only if' form of wording; two being of the form 'p only if q' for the positive conditional, and two being 'q only if p' for the doubly negated conditional 'If not-p, then not-q' ('q only if p' being logically equivalent to 'If not-p, then not-q'). Hence 'only if' conditional wording was used only where there was no other possible

wording which would completely eliminate the need for negation. No subject produced even one 'If, then' conditional. This might suggest that conditional wording, particularly in the 'If, then' form, is an unfamiliar way of expressing relations of the kind concerned. If this were the case it might account for some of the difficulty of the standard selection task. On the other hand, the absence of 'If, then' conditionals in subjects' formulations may be an artefact of the particular task they were presented with. Since the whole task is to specify the conditions under which pairs of cards must be accepted or rejected, the whole response must have the semantic force of a biconditional: a pair can be accepted 'If, and only if' certain conditions are satisfied. To express the required conditions themselves in a conditional form would therefore require the embedding of one conditional within another. An example of such a formulation would be; "If a pair is such that if the letter is a 'B' then the number is a '3', then accept it. Otherwise reject it". (The second sentence changes the form of the whole rule from a conditional to the required biconditional by adding the 'and only if' element). Sentences of this form are surely unlikely to be considered maximally comprehensible. This may be contrasted with the equivalent conjunctive rule; "If a pair contains a 'B' without a '3', then reject it. Otherwise accept it".

Because this experiment required subjects to include their statement of the relevant relation within a broader rule, the responses cannot be taken to indicate reliably how the relation would have been described if this requirement had been absent. In particular, the infrequency of conditionals may be misleading. However the choice of alternatives to the conditional form cannot be affected by avoidance of multiple embedding of the same kind of relation. Subjects' preferred formulations are therefore of evidential value.

It is notable that each of the four variants of the relation has

exactly one kind of formulation which avoids negation of individual items (as opposed to the global negating function of the first 'not' in 'Not both p and not-q'. Of the 44 responses using these formulations, 22 (50%) of responses were of the one which avoids negation, compared with a chance probability of 33% that the least negated form would be selected. This tendency to avoid negation, combined with a tendency to prefer the '-(p &-q)' formulation appears to underly the very strong preference for the '-(p & q)' variant in the appropriate case, with 11 out of 12 (92%) responses being of this kind.

Of the four remaining responses, three were unclassifiable. These three responses were made by the same subject and contained direct references to the truth table such as "Accept first three cards". In the subsequent selection task these three formulations elicited the selection "None" from the subject concerned. The remaining response which could not be classified with any of the others was made in response to the 'If not-p, then not-q' table. It was worded "If the letter is 'B' then accept; if the letter is not 'B' and the number is '3' then accept". The nearest equivalent logical form to this appears to be 'p or (not-p and q)'. Since the counterexample is 'not-p and q' in this case, it seems that this response was simply a mistake. Probably the subject intended to make 'reject' the final word, in which case it would have constituted a correct instance of the '-(-p & q)' case of the general form '-(p & -q)'.

Table 5.2

Numbers of correct responses to each formulation of the relation

Conditional Equivalent	p -> q	p -> -q	-p -> q	-p -> -q	Total
p only if q	1	0	0	1	2
-(p & -q)	4	8	4	4	20
-p v q	1	1	4	0	6
Total	6	9	8	5	28
Standard Formulation	3	4	1	2	10

Table 5.2 shows the numbers of correct responses on subjects' own formulations of the task and on the standard formulations. The difference in the numbers of correct responses (28 / 48 on own formulations, 10 / 48 on standard formulations) is highly significant ($p = 0.005$, one-tailed Wilcoxon Matched-Pairs Signed-Rank Test).

Hence it appears that subjects are likely to formulate the problem for themselves in ways which facilitate solutions. Sevety-five percent of subjects' own formulations were of a potentially facilitatory kind if these are taken to include the 'Not both p and not-q' formulations and the positive disjunctive formulation 'p or q'. This suggests that where relations such as those obtaining between the items in the selection task are encountered in people's experience of the world, speakers will discuss them with hearers in such terms that the latter are likely to make the correct inferences. Hence normal linguistic practice is likely to minimize the difficulty of the inferences which hearers are required to make. Subjects' performance on the conditionally worded selection task may therefore be a poor guide to the validity of the inferences they are likely to be called upon to make in real-life conditions.

Where subjects' own formulations were used, 20 of the 28 correct responses (see Table 5.2) occurred in response to the 29 'Not both p and not-q' formulations in the four forms possible when the negation of p and q is permutated. This formulation proved to be the most facilitatory, with a 69% frequency of correct solutions. This facilitation could arise because the counterexample is more obvious when a 'Not both p and not-q' formulation is used, or because higher-order matching would result in the correct response. The question as to which of these cognitive routes is involved in the observed facilitation will be further investigated in Chapter 5.

Disjunctive formulations elicited 6 correct responses with the 11 formulations which were of this kind (55% correct), but 4 of the 6 correct responses occurred on the positive 'p or q' formulation, and could not therefore be explained by any kind of matching bias since the correct response is '-p, -q'. It therefore appears that disjunctive formulation makes the counterexample more available, probably because, as previously argued, the semantic criterion of validity of 'either p or q' is easily seen to include the falsity of 'neither p nor q'.

One subject gave correct responses to his two 'only if' formulations, while the other subject who produced two such formulations selected all four cards when this wording was included in the selection task.

As remarked above, it remains unclear whether the facilitation observed with the 'Not both p and not-q' formulations is due to the greater accessibility of the counterexample or to higher-order matching, or both. Moreover, the apparent indication that the 'Not both p and not-q' form is facilitatory is in conflict with the results of Van Duyne (1974) and Legrenzi (1970) which have cast some doubt on the facilitatary

nature of this form of wording. Van Duyne compared performance on problems with conjunctive wording, the standard conditional wording and two other forms of words. These four problems had symbolic content and Van Duyne used different content items in each of them. Of the 24 subjects participating, 3 responded correctly to the conditionally worded problem and the conjunctively worded version elicited 4 correct responses. First-order matching responses of 'p,q' or 'p' alone were observed on the conditional problem in 12 cases (50%) and on the conjunctive problem in 13 cases (54%). This leaves open the question as to whether the high incidence of first-order matching was due to the differing content items between problems, which could have led to the items being perceived as multiple, or to the particular form of wording used by Van Duyne.

Similarly, Legrenzi (1970) used the sentence; "It is not possible for there to be a vowel on one side of a card and not an even number on the other side", written in Italian. His experiments included a single form of binary symbolic content. He found no facilitation (1 correct response from 15 subjects) with a conjunctive form of words, and there were 11 'p, q' first-order matching responses.

To summarize these contrasting observations, Experiment 5 suggests that the 'Not both p and not-q' formulation is facilitatory, and the results of Van Duyne (1974) and Legrenzi (1970) suggest that it is not facilitatory and that it elicits many errors due to first-order matching. The reason for these conflicting observations needs to be determined, and an attempt to do so is made in Chapter 5. One possibility is that the 'Not both p and not-q' form is not normally facilitatory, but that the facilitation observed in the present experiment was a result of the fact that the sentences were in subjects' own words and reflected their individual preferences and linguistic experience. In order to test this conjecture Experiment 6 compares performance on the standard wording with

performance on a form of the 'Not both p and not-q' wording. The subjects were drawn from the same population as those participating in Experiment 5, but in the case of Experiment 6 the sentences used in the problem were formulated by the experimenter and not by the subjects.

Experiment 6

INTRODUCTION

In this experiment performance on the four variants of the 'If p, then q' worded selection task including negation was compared with performance on four logically equivalent tasks using the conjunctive form of words 'Not both p and not-q'. The aim was to establish whether this latter formulation is, by itself, facilitatory to a sufficient extent to account for the facilitation observed in Experiment 5. The experimental hypothesis was that on versions of the selection task with binary content this form of words would elicit more correct solutions than the standard conditional wording.

METHOD

Subjects

Twenty-four Keele University undergraduates participated on a voluntary basis.

Materials, Design and Procedure

Printed booklets were used containing a sheet of instructions and eight selection tasks (see Appendix D). The tasks were presented in the form of diagrams of four pairs of cards. On the left-hand card of the first and second pairs were the letters 'B' and 'C' respectively, and on the right-hand cards of the third and fourth pairs were, respectively, the

numbers '3' and '4'. The other card in each pair was left blank to represent a face-down card. The instructions asked subjects to put a tick in the blank rectangle(s) representing the face-down card(s) they would need to turn over in order to decide whether the statement accompanying the diagram on each page was true.

The order of presentation of the tasks was counterbalanced between subjects, with the constraint that the two forms of wording appeared alternately. The relevant sentences in the standard condition were expressed as "If the letter is B, then the number is 3"; and in the conjunctive condition the wording was "There is no pair which can be described as follows: the letter is B and the number is not 3". This form of words was intended to resemble in a general sense the formulations of subjects who used conjunctive wording in Experiment 5, since the intention was to establish whether the wording observed there was the source of facilitation. It differs from the wording of Legrenzi (1970) described above, and from that of Van Duyne (1974);"It isn't the case that a card has a 'B' on one side and doesn't have a '3' on the other side". The wording of both these researchers applied to the double sided cards they used, and included, in the case of Van Duyne, only this form of words and in the case of Legrenzi this form of words and also a 'Not both p and q' variant.

Subjects, either singly or in small groups, were presented with the booklets of problems and asked to read the instructions. They were requested to proceed with the problems in the order given when they had understood the instructions.

RESULTS AND DISCUSSION

Table 6.1 shows the frequencies with which subjects chose all

possible card combinations for all variants of the conditional and conjunctive formulations. Selections on conjunctive formulations are described in relation to the equivalent conditional formulation. For example, on the '~(p&q)' variant a selection of 'q' is counted as an 'FC' selection because the equivalent conditional rule is 'p → ~q'.

TABLE 6.1

	Conditional				Conjunctive			
Variant	p->q	p-> -q	-p->q	-p-> -q	-(p&-q)	-(p&q)	-(-p&-q)	-(-p&q)
SELECTION	*	*	+	+	*	*	+	+
TA	4	2	3 *	1 *	2	1	1 *	1 *
FA	0	0	0	1	1	0	0	0
TC	2	0	1	0	0	1	0	0
FC	0	1	0	0	0	1	1	1
TA,FA	0 *	0 *	0 +	0 +	0 *	0	0	1
TA,TC	13	9 *	13	9	3	0 *	2 +	1
TA,FC !	1	6	1 *	7	12 +	19	13 *	16 +
FA,TC	0	1	0	0 *	1	1	4	1 *
FA,FC	0	0	0	3	1	1	0	1
TC,FC	0	0	0	0	0	0	0	0
TA,FA,TC	0	0	2	0	0	0	0	0
TA,FA,FC	0	0	0	0	0	0	0	2
TA,TC,FC	3	5	3	2	4	0	1	0
FA,TC,FC	0	0	0	0	0	0	0	0
All cards	1	0	1	1	0	0	2	0
No cards	0	0	0	0	0	0	0	0
			Total			Total		
! = correct solution			15			60		
* = first-order matching			29			30		
+ = higher-order matching			35			43		

Table 6.1 shows that of the 96 solutions in each condition, 13 were correct on the conditional task and 60 correct on the conjunctive task. This difference is significant at the $p = 0.0001$ level (one-tailed Wilcoxon). Hence the experimental hypothesis was confirmed. The difference observed is larger than the difference in correct solutions between the two conditions in Experiment 5, being in the proportion 4:1 rather than just under 3:1. In the case of the conjunctive problem it is possible to attribute the 60 correct responses to matching, since matching (including higher-order matching to negated items) to the content items mentioned always yields the correct answer to the conjunctive problems. In total, there were 73 (76%) matching responses to the conjunctive problems, and 64 (67%) to the conditional problems. Of the 13 matching responses to the conjunctive problems which did not yield correct solutions, 5 were selections of the correct letter card alone and 8 were cases of first-order matching to negated variants.

With the standard conditional formulation in the present experiment all subjects showed a marked tendency to select the TA card (86) rather than FA (11). The main difference between subjects' selection patterns was in their choices of a consequent card. The choice of a consequent card may indicate the basis on which its selection was made more clearly than the choice of an antecedent card, which might be influenced by directional bias. For example, Subject 14 chose the TA and FC cards on all four conditional variants of the task, giving four correct responses. This suggests that Subject 14 was using a logically correct response strategy. This subject was a computer science student who may well have been familiar with the truth-conditions of conditional statements.

Two of this subject's responses could also be described as choices of the TA and 'q' cards; but it would clearly be inappropriate to use this

description since the 'q' card was selected only on variants of the problem in which the consequent was negated. However, where 'q' card selections predominate in a subject's responses the existence of an underlying first-order matching bias is suggested. This was the case for 8 of the subjects who between them selected 26 'q' cards and only 6 '-q' cards.

The responses of the remaining 15 subjects were most strongly characterized by a tendency to select the TC card (46) rather than the FC card (19). This pattern of selections of these 15 subjects suggests that they were primarily influenced by higher-order matching bias. Indeed, six of these subjects responded completely consistently with 'TA, TC' on all four variants of the conditional task. These results indicate considerable variability between individuals in their tendency to match on a first-order or higher-order basis.

The fact that responses tend to be consistent betweeen subjects in the choice of the TA card and variable in the choice of a consequent card has implications for the analysis of selection task data. One implication is that consequent card selections on variants of the task with negated consequents can provide a good indication of the kind of matching bias which has influenced those selections. On these variants, selections of the 'q' card are associated with first-order matching and selections of the '-q' card are associated with higher-order matching. Hence comparison of the numbers of selections of each of these cards should provide a good indication of the relative predominance of the two forms of matching bias.

A further implication of the results of Experiment 6 is that, because of the individual variation in consequent card choice, the proportion of responses of the two kinds is of less interest than is its change in response to an independent variable such as the binary or multiple content

used in Experiment 1. The relative frequency of first-order and higher-order matching might vary considerably between populations and could disguise a bi-modal distribution within a population. What is of more interest for the present research is the change in the numbers of responses of each kind which is observed in response to an independent variable such as binary or multiple content.

The data obtained in Experiment 1 might usefully be reanalyzed in this way, and the results may be compared with those of a similar analysis of the other studies mentioned in connection with Experiment 1.

Implications for Experiment 1

It will be recalled that on variants of the task which have a negated consequent the first-order matching selection is 'q' (FC) and the higher-order matching selection is '-q' (TC). On such problems, the tendency to select 'TA,TC' rather than 'TA,FC' should indicate the extent to which there is a tendency to select a consequent card on the basis of higher-order matching bias. The results of Experiment 1 will be reanalysed in this way by comparing the numbers of selections of 'TA,TC' and 'TA,FC' on the problems with negated consequents. This eliminates from the comparison the antecedent card choices, which could have been influenced by directional bias and therefore constitute more equivocal data.

TABLE 6.2

Choices on sentences with negated consequents in Experiment 1.

	Abstract Binary	Thematic Binary	Abstract Multiple	Thematic Multiple
TA,TC	10	12	7	8
TA,FC	4	0	4	8
Diff.	6	12	3	0

Comparing the binary versions with the multiple versions we have:

TABLE 6.3

Choices on sentences with negated consequents in Experiment 1.

	Binary	Multiple	diff.
TA,TC	22	15	7
TA,FC	4	12	-8
Diff.	18	3	15

The figure of '15' at the bottom right of the table represents the combined decrease in first-order matching and increase in higher-order matching when binary rather than multiple content is involved. This figure represents 25% (15/60) of all the responses made to the variants with negated consequents. It is therefore a measure of the magnitude of change in the kind of matching bias on the basis of which responses were made. The change in the basis of responding, measured in this way, between the binary and multiple conditions in Experiment 1 is significant at the $p < 0.025$ level (one-tailed Wilcoxon). A similar comparison between the numbers of these responses in the abstract ($17 - 8 = 9$) and thematic ($20 - 8 = 12$) conditions shows a difference ($12 - 9 = 3$) which is short of significance. This again illustrates that the differences observed are due to the different types of matching response to multiple and binary content, and not to verification bias or to the realism of the content.

By using this measure as a basis for comparison with the other results considered in discussing Experiment 1 it is possible to illustrate the extent of this change in responding, independently of the absolute frequency of the two types of bias in these experiments. The figures are as follows:

TABLE 6.4

Choices on variants with negated consequents in two experiments.

Griggs and Cox, 1983.

	Binary	Multiple	diff.
TA,TC	9	3	6
TA,FC	9	18	-9
Diff.	0	-15	15

Magnitude of change = 37%

Reich and Ruth, 1982.

	Binary	Multiple	diff.
TA,TC	14	4	10
TA,FC	12	12	0
Diff.	2	-8	10

Magnitude of change = 21%

It can be seen in tables 6.3 and 6.4 that in Experiment 1 there was more higher-order consequent matching ('TA, TC' responses) than in the studies of Griggs and Cox (1983) and Reich and Ruth (1982). The Reich and Ruth study differs from the others in that all of the change occurs in the frequency of higher-order matching, while the other two studies show approximately equal effects on both kinds of matching. However, there is more consistency in the overall size of the change in responses as shown

by the figures for the 'Magnitude of change'. For all three studies it is in the range 20-40%. This figure represents the proportion of responses in which first-order consequent matching ceases to occur or higher-order consequent matching begins to occur on the binary problems. It also indicates the source of correct solutions on the multiple problems with negated consequents in Experiment 1: namely, first-order consequent matching yielding 'TA,FC' responses.

Comparison of Experiment 6 with other studies

The 'TA,FC' row of Table 6.1 shows the numbers of correct solutions to each of the 8 variants of the problems. The four conjunctive variants in columns 5 to 8 are arranged in order of logical equivalence to the conditional variants in columns 1 to 4 respectively, ie; '-(p&-q) in column 5 is logically equivalent to 'p -> q' in column 1, and the same applies to columns 2 & 6, 3 & 7 and 4 & 8. Comparing numbers of correct solutions on each conditional sentence with its conjunctive equivalent, there was little difference between the amount of facilitation observed on each of the four variants of the sentence.

Van Duyne (1974) and Legrenzi (1970) found no facilitation using 'Not both p and not-q' wording compared with 'If p, then q' wording, in their initial forms (ie; without varying negation). In the present experiment the comparable positive conditional "If the letter is B, then the number is 3" elicited one correct solution, while its conjunctive equivalent "There is no pair which can be described as follows: the letter is B and the number is not 3" elicited twelve correct solutions. This difference is significant at the $p < 0.001$ level (one-tailed sign test). Hence it has been confirmed that under the conditions of the present experiment the

'Not both p and not-q' form of wording is facilitatory. In the remainder of the present chapter the reasons underlying the conflicting findings of Van Duyne (1974) and Legrenzi (1970) will be investigated. This will be attempted by using conjunctively worded problems which are more similar to those used by Van Duyne (1974) in order to observe whether a similar result is obtained.

INTRODUCTION

It has been noted above that in Experiment 6 results were obtained which contrasted with those of Van Duyne (1974) and Legrenzi (1970) whose findings showed no facilitation when conjunctive wording was used. The facilitatory effect of conjunctive wording in Experiment 6 was also supported by the results of Experiment 5, where subjects own conjunctive formulations resulted in a high proportion of correct responses. It therefore appears that some unremarked difference between the problems presented to subjects in Experiments 5 and 6 and those used by Van Duyne and Legrenzi must have been responsible for the difference in facilitation. Since the wording of the problems in Experiment 5 was elicited from the subjects themselves, and a similar 'natural' style of wording was used in Experiment 6, it seems that the crucial difference in the wording might have been the logic-based formality of phrases used by the other experimenters. In the case of Van Duyne's wording the phrase 'It isn't the case that ...' always occurred in his conjunctive problems; and Legrenzi's conjunctive problems all began with 'It is not possible for there to be ...' (in Italian; 'Non e possibile che ci sia ...'. To attribute such considerable differences in facilitation in a post hoc manner to such a vaguely defined variable as 'naturalness' would be to abandon the investigation before it had properly begun. It was therefore decided to attempt to discover whether a single definable feature of the wording was responsible for the differences observed. The method adopted was a 'binary chop' elimination strategy. This would involve formulating the conjunctive problems in a way which was intuitively about half way between the formulations in Experiment 6 and those of Van Duyne (1974).

If the facilitation were to disappear under those conditions, the next move would be to use a formulation half way between the most recent one on that used in Experiment 6. If, on the other hand, the facilitatory effect were to persist with the new formulation, then a formulation even closer to that of Van Duyne could be tried.

The two conditions in the present experiment are therefore identical to those in Experiment 6, except that the conjunctive versions of the task are worded "It isn't the case that a pair contains both a letter which is 'B' and a number which is not '3'", and the three variants generated by permutating the occurrence of the negating term 'not'. It will be recalled that the wording in Experiment 6 was "There is no pair which can be described as follows: the letter is B and the number is not 3". The general experimental hypothesis was that the conjunctively worded variants would elicit more correct responses than the conditionally worded variants. In view of the results of Experiment 6 it seems plausible that the effect of Van Duyne's wording was to minimize, rather than to completely eliminate, the apparently strong and robust phenomenon of higher-order matching. Van Duyne's results also support this conclusion, since he observed 4 / 24 correct (higher-order matching) responses. In addition, the wording in the present experiment was a hybrid of the wording in Experiment 6 and that of Van Duyne (1974). It was therefore hypothesized that there would be more correct responses to the particular variant of the conjunctive problem 'Not both p and not-q' than to the particular conditional variant 'If p, then q'. The main aim of the experiment was to eliminate possible sources of the differences in facilitation previously described; and this would be achieved whether or not the facilitation hypothesis was supported. An intermediate result would provide grounds for accepting an explanation based on the 'naturalness' of the formulation used.

METHOD

Subjects

Eighteen Open University students at a summer school at Keele University participated on a voluntary basis. Of these one had to be eliminated from consideration because the blank boxes representing face-down cards were filled in with letters or numbers instead of being ticked.

Materials, Design and Procedure

These were as in Experiment 6, except for the different wording of the relevant sentences in the conjunctive condition.

RESULTS AND DISCUSSION

Table 7.1 shows the frequencies with which subjects chose all possible card combinations for all variants of the conditional and conjunctive formulations. Selections on conjunctive formulations are described in relation to the equivalent conditional formulation, as in Table 6.1.

TABLE 7.1

	Conditional				Conjunctive			
Variant	p->q	p-> -q	-p->q	-p-> -q	-(p&-q)	-(p&q)	-(-p&-q)	-(-p&q)
SELECTION	*	*	+	+	*	*	+	+
TA	3	3	4	3	4	3	1	0
			*	*			*	*
FA	0	2	0	2	0	0	2	2
TC	2	0	0	0	0	0	0	0
FC	0	1	0	0	0	1	0	0
TA,FA	0	1	0	0	0	0	0	0
	*	+	+	+	*			
TA,TC	7	3	5	6	2	0	3	3
		*			+	*	+	+
TA,FC !	2	5	3	3	5	7	7	8
			*				*	
FA,TC	1	2	3	0	1	4	3	2
				*				*
FA,FC	2	0	0	3	3	1	1	2
TC,FC	0	0	0	0	0	1	0	0
TA,FA,TC	0	0	0	0	0	0	0	0
TA,FA,FC	0	0	0	0	0	0	0	0
TA,TC,FC	0	0	0	0	0	0	0	0
FA,TC,FC	0	0	0	0	1	0	0	0
All cards	0	0	2	0	1	0	0	0
No cards	0	0	0	0	0	0	0	0

	Total	Total
! = Correct selection	13	27
* = First-order matching	26	25
+ = Higher-order matching	21	21

There were 13 correct solutions of the conditional problems and 27 correct solutions of the conjunctively worded problems. This difference is significant at the $p < 0.02$ level (one-tailed Wilcoxon). Hence instead of the fourfold increase in correct solutions in Experiment 6 in the conjunctive condition, correct solutions were only slightly more than doubled in number. Seven of the correct responses to the conditional problems were produced by two subjects who also gave correct solutions to all the conjunctive problems. If these subjects are separately classified as using a logical strategy, the difference in correct solutions for the remaining subjects is threefold (conditional 6, conjunctive 19).

The incidence of matching responses was remarkably similar in both conditions. First-order matching accounts for 26 (38%) responses to the conditional problems and 25 (37%) to the conjunctive problems. Higher-order matching accounts for 21 (31%) responses to both sets of problems. This yields a total of 47 (69%) matching responses to the conditional problems and 46 (68%) in the conjunctive condition. The similarity of these figures suggests that the majority of subjects were consistently responding on the basis of matching bias, and that higher-order matching is responsible for the greater number of correct responses to the conjunctive problems. This finding is consistent with the results of Experiment 6, except that there was rather more higher-order matching on the conjunctive problems in that experiment (45%, compared with 31% in the present experiment). This difference, if it were found to be reliable, might be attributable to the more natural wording of the conjunctive problems in Experiment 6.

A more important difference between the present results and those of Experiment 6 is that the difference in correct solutions to the positive conditional (2) and its conjunctive equivalent (5) is not significant. At first sight, this result appears to confirm Van Duyne's (1976) finding of

no significant difference between these two variants of the task. However, the difference between performance on these two variants was comparable with that observed between the other logically equivalent variants (see Table 7.1). Since the combined effect was significant the lack of significance in the particular comparison concerned may be due to the smallness of the sample. Hence, while it seems justifiable to conclude that the present experiment has shown a genuine reduction in higher-order matching and correct responding to the conjunctive problems compared with experiment 6, the present result may represent an attenuated demonstration of the effects observed in Experiment 6. The observed responses may be a result of wording which might have been less comprehensible than that used in Experiment 6; but there appear to be no grounds on which to base a stronger or more specific conclusion. In order to confirm and explain Van Duyne's (1974) finding a further experiment is required using wording even more similiar to Van Duyne's, and with more subjects participating, in order to observe whether a further 'binary chop' would eliminate the overall facilitatory effect observed in the Experiment 7. Experiment 8 was therefore devised in order to fulfil this requirement.

INTRODUCTION

This experiment was intended to be a partial replication of that of Van Duyne (1974): comparing performance on selection tasks having conjunctive and conditional wording identical to the wording used by Van Duyne (1974). To this end it was also necessary to present the stimuli as four double-sided cards, rather than four pairs of cards as in the previously described experiments 5, 6 and 7. It was also an extension of Van Duyne's study in the sense that all four variants which are made possible by the inclusion of negation were used for both the conditional and conjunctive versions of the task. Hence comparison is again possible with Legrenzi's (1970) study in which two of the four variants of the conjunctive formulation (Legrenzi's Experiments 2 and 3) were compared with each other and with a conditional formulation (Experiment 1).

The broad experimental hypothesis was that there would again be more correct solutions of the conjunctively formulated task. Of greater interest was whether the conjunctive form without internal negation '~(p & q)' would prove to be maximally facilitatory as in Legrenzi's (1970) Experiment 3, and whether the '~(p & ~q)' form would produce minimal facilitation as in Legrenzi's (1970) Experment 2 and the study by Van Duyne (1974). Since the comparable conditions in the present experiment were identical with those of Van Duyne (1974), a similar result is to be expected for these conditions.

METHOD

Subjects

Twenty-nine undergraduates of Keele University and of the Open University participated on a voluntary basis.

Design Materials and Procedure

These were as in Experiment 6, except that the stimuli used were diagrams of four double-sided cards showing respectively the symbols 'B', 'C', '3' and '4', and subjects were asked in the printed instructions which of these they would need to turn over in order to decide whether the accompanying statement was true or false of the cards.

In the conditional form the statement was expressed in the words; "If a card has a B on one side, then it has a 3 on the other side", and by the three negated variants of this sentence. The following is an example of the negated wording; "If a card doesn't have a B on one side, then it doesn't have a 3 on the other side".

In the conjunctive form the wording was; "It isn't the case that a card has a B on one side and doesn't have a 3 on the other side", and the three variants made possible when different combinations of the content items are affirmed or negated. Each subject attempted all 8 problems (4 conditional and 4 conjunctive) which were presented in counterbalanced order with the constraint that conjunctive and conditional problems alternated and, as far as possible, each variant appeared equally frequently in each serial position. All the internal negatives were worded as shown above (ie; "doesn't have a B" and "doesn't have a 3"). Compare Experiments 6 and 7 where all internal negatives were worded as "not B" and "not 3" (see p.105 for examples of the conjunctive wording).

RESULTS AND DISCUSSION

Table 8.1 shows the frequencies with which subjects chose all possible card combinations for all variants of the conditional and conjunctive formulations. Selections on conjunctive formulations are described in relation to the equivalent conditional formulation as in Table 6.1.

TABLE 8.1

	Conditional				Conjunctive			
Variant	p→q	p→ ¬q	¬p→q	¬p→ ¬q	¬(p&¬q)	¬(p&q)	¬(¬p&¬q)	¬(¬p&q)
SELECTION	•	•	+	+	•	•	+	+
TA	9	8	8	7	2	8	2	3
			•	•			•	•
FA	0	1	0	0	0	1	2	2
TC	2	1	2	0	3	0	1	0
FC	0	2	0	1	2	0	2	5
TA,FA	2	0	2	0	1	1	1	1
	•	+	+	+	•			
TA,TC	14	0	10	7	15	2	3	3
		•			+	•	+	+
TA,FC !	0	13	1	2	1	14	10	4
			•				•	
FA,TC	0	0	2	0	0	2	5	0
				•				•
FA,FC	0	0	0	7	1	0	0	11
TC,FC	0	1	1	0	2	1	0	0
TA,FA,TC	0	1	0	0	0	0	0	0
TA,FA,FC	0	0	0	0	0	0	0	0
TA,TC,FC	0	1	2	4	2	0	1	0
FA,TC,FC	0	0	0	0	0	0	1	0
All cards	2	0	0	1	0	0	1	0
No cards	0	1	1	0	0	0	0	0

	Total	Total
! = Correct solution	16	29
• = First-order matching	53	59
+ = Higher-order matching	32	20

As in Experiments 6 and 7, there were more correct responses to the conjunctive problems (29) than to the conditional problems (16); ($p < 0.05$, one-tailed Wilcoxon). Hence the experimental hypothesis was confirmed.

Table 8.2 shows the percentage figures for correct responses to the two conjunctive variants mentioned in the introduction to the present experiment and for three comparable experiments which were mentioned previously.

TABLE 8.2
Percentage of correct responses to two conjunctive variants of the selection task in four studies.

	$-(p \,\&\, -q)$	$-(p \,\&\, q)$
Experiment 8	3	48
Van Duyne (1974)	17	-
Legrenzi (1970) Expt 2	-	77
Legrenzi (1970) Expt 3	7	-

It it noteworthy that in the conditions which are directly comparable with those of Van Duyne (1974) and Legrenzi (1970) subjects' selections were similar to those observed by these researchers. There was little facilitation in the $-(p \,\&\, -q)$ conditions, and considerable facilitation in the $-(p \,\&\, q)$ condition. The low level of correct responses to the $-(p \,\&\, -q)$ variant (3%) may be contrasted with the level observed in Experiment 7 (29%) and more strongly with performance in Experiment 6 (50%). In the present experiment, the tendency to respond correctly to the $-(p \,\&\, -q)$ variant seems to have been replaced by a tendency to give the first-order matching response 'p, q'. Fifty-two percent of the responses were of this kind.

In the conjunctive condition 24 of the 29 correct responses occurred on the two variants of the problem with neither or both content items negated; 14 correct responses on 'Not both p and q' and 10 correct responses on 'Not both not-p and not-q'. Where the content items differed in terms of negation, correct responses were rare; 1 on 'Not both p and not-q' and 4 on 'Not both not-p and q". It will be recalled that Van Duyne (1974) and Legrenzi (1970) observed few correct responses to the 'Not both p and not-q' formulation. This is in accordance with the broader pattern of results in the present Experiment 8 and may be due to an effect of the number of internal negations on the type of matching observed. On the doubly negated 'Not both not-p and not-q' form there were only 8 first-order matching responses, while on the positive 'Not both p and q' form there were 22 such responses. The other two forms elicited respectively 20 and 18 such responses.

Since performance on the problems appears to have been more affected by matching biases than by logical strategies, as in the previous two experiments, it will be useful to compare the incidence of the two kinds of bias in both conditions. For this purpose, in Table 8.3, variants of each condition are paired, not by logical equivalence, but by similarly negated content items. On the conjunctive problems, unlike the conditional problems, there is no reason to expect a directional effect on selections. Therefore the selection of either conjunct alone - not just the p or not-p card - is taken to demonstrate first-order or higher-order matching bias. Selections of consisting of both one letter and one number are treated similarly in both conditions.

TABLE 8.3

Incidence of two types of matching response on conditional and conjunctive problems with four types of content.

	Higher-order matching		First-order matching		-> = Conditional & = Conjunctive
	->	&	->	&	
p, q	-	-	23 *	22 (14) *	
p,-q	0	3 (1) *	21 (13) *	20	
-p, q	18	7 (4) *	2	18	
-p,-q	14	14 (10)	7	8	

Variants of the problem where matching to one number card and one letter card yields the correct response are indicated by '*'. The actual number of correct responses is shown in parentheses. The difference represents single-card matching selections.

Potential sources of the correct solutions are, therefore, first-order matching on 'If p, then not-q' and 'Not both p and q', and higher-order matching in the other conjunctive conditions. Correct solutions to other conditional variants were very infrequent, varying from 0 to 2. The influence of these biases on the distribution of correct (two-card) solutions is clearly considerable, correct solutions occurring at very close to 2/3 of the frequency of responses showing the relevant bias.

On the conditional problems the incidence of first-order matching responses was at least as high (46% or 53/116) as for any of the multiple content conditionals previously discussed, despite the binary content of the present version. In fact both forms of matching were present in very similar proportions to those observed on the multiple version of

Experiment 1. The figures for matching responses were: first-order, Expt 8, 46%; Expt 1, 45%; higher-order, Expt 8, 28%; Expt 1, 25%. This high incidence of first-order matching would explain the occurrence of 13 correct solutions to the 'If p, then not-q' variant, where the 'p,q' response produced by first order matching is, in fact, the correct response. The other three variants elicited respectively only 0, 1 and 2 correct responses.

Hence, for both the conjunctive and conditional problems, an explanation of the distribution of these two kinds of bias would also constitute an explanation of the origin of the correct solutions. Table 8.3 shows that the distribution of these matching tendencies is similar in all conditional and conjunctive cases except those with '-p,q' content. The high incidence of first-order matching responses to both versions of the problem in the present experiment clearly requires explanation, since this feature of the responses stands in marked contrast to the responses observed in the previous experiments. Hence only performance on the negated forms requires any detailed examination because, where the content is 'p,q', only first-order matching is possible and it occurs with similar frequency on both formulations.

Considering the conditional cases first, the distribution of first-order matching bias may be compared with that observed in the previous three experiments.

TABLE 8.4.

Incidence of first-order matching responses to negated conditional problems

	p -> -q	-p -> q	-p ->-q
Experiment 5	4	1	1
Experiment 6	8	0	4
Experiment 7	8	3	5
Total	20	4	10
Experiment 8	21	2	7

Clearly a very similar distribution of first-order matching is being observed, but first-order matching responses are much more frequent overall in Experiment 8. The reason for this latter feature can only be the wording of the conditional sentence, and not the references to double-sided cards for the following reason. The conditional problems in Experiment 1 resembled those in the present experiment in referring to double-sided cards. In addition, the abstract problems in Experiment 1 had content similar to that used in the present experiment. Despite these similarities, first-order matching was much less frequent on the binary problems in Experiment 1 than on the (binary) problems in the present experiment. The difference in responses to the conditional problems would therefore appear to be due to some other feature in respect of which the conditional problems in Experiment 8 differ from those in Experiment 1. This feature could also be expected to be common to the problems used by Legrenzi (1970) and Van Duyne (1974), since they elicited

similar responses to those observed in Experiment 8.

There is a consistent way in which the wording in the present experiment is similar to that used by Legrenzi (1970) and differs from that used in Experiments 1, 6 and 7. The present wording; "If a card has a B on one side, then it doesn't have a 3 on the other side" separates the negating expression 'doesn't' from the negated term '3' in a way that the wording in the other experiments 'not 3' does not. This is analagous to a feature of the conjunctive wording in Legrenzi's (1970) Experiments 2 and 3 where the wording was "un numero dispari" and "non ci sia un numero pari" respectively. The closeness of the negating term 'dis-' in 'dispari' (in Italian "dispari" is the only word for "odd", as though the only English word for "odd" were "uneven") in the first case is to be contrasted with the distance of the negating term 'non' from 'pari' in the second case. The Italian word order 'not there is' rather than the English 'there is not' makes the even greater distance possible. It therefore seems that the prevalence of first-order matching on the conditional problems is due to the relative difficulty of converting 'doesn't have a 3' to 'has a 4', compared with converting 'not 3' to '4'. It therefore appears that Van Duyne's (1974) wording (identical to that used in the present experiment) is sufficient to considerably reduce higher-order matching in favour of first-order matching. In Experiment 1 it was observed that where content differs between sequentially presented problems, there tends to be more first-order matching. The fact that Van Duyne's content items differed betweeen problems in this way could therefore have added to the effect of the wording of the negated terms in such a way as to counteract the potentially facilitatory effect of the conjunctive wording. In the present experiment, however, the content was the same for all problems and identical to that used in the previous experiments. Hence the observed effect is here attributed to the verbal formulation of the problem.

As shown on Table 8.4, first-order matching bias occurred most frequently on the conditional variant with a positive antecedent 'If p, then not-q' (21 cases) than on the two with negated antecedents (a total of 9 cases). This difference is highly significant ($p < 0.002$; two-tailed sign test) and is entirely consistent with the well-established tendency to select TA rather than FA which was discussed under 'Directional Bias' in Chapter 1. The 'If p, then not-q' variant elicited the majority of the correct responses, 13/16. First-order matching appears to be largely responsible for the correct solutions to this variant of the problem. The predominence of first-order matching on this variant appears to be a consequence of the previously mentioned tendency to select TA rather than FA. Alone among the negated variants, 'If p, then not- q' has a TA card which is the same as the p card. Whether an antecedent card is selected because it is the TA card or because it is the p card, first-order matching will appear to determine the antecedent card selection on this variant of the task. Hence more first-order matching is observed on this variant than on the two variants with negated antecedents: 'if not-p, then q' and 'If not-p, then not-q'.

Conjunctive Problems

Performance in the present experiment differs considerably from that observed in the previous experiments. This difference occurs on the two singly negated forms 'Not both p and not-q' and 'Not both not-p and q' where, by contrast with the previous experiments, first-order matching predominates. However, the doubly negated form 'Not both not-p and not-q'in the present experiment elicited more higher-order (14) than first-order (8) matching responses.

It would appear that this difference between variants of the conjunctive problem must be attributed to the different ways in which the content items are negated. The wording of the two variants which elicit a preponderence of first-order matching responses are as follows:

"It isn't the case that a card has a B on one side and doesn't have a 3 on the other side"

"It isn't the case that a card doesn't have a B on one side and has a 3 on the other side"

The only explanation of this effect which appears to be consistent with the different responses to the doubly negated form; "It isn't the case that a card doesn't have a B on one side and doesn't have a 3 on the other side", is that the external negation "It isn't the case that" is understood by subjects to cancel only one internal negation "doesn't have a", the two negatives making a positive. For example, the wording "It isn't the case that a card has a B on one side and doesn't have a 3 on the other side" may lead subjects to infer correctly that "Every card which has a B on one side has a 3 on the other side", or make a similar inference which would suggest that the relevant items were B and 3. From this point only first-order matching is possible, yielding the response 'B and 3'. On the other singly (internally) negated conjunctive variant "It isn't the case that a card doesn't have a B on one side and has a 3 on the other side" subjects may again infer, this time invalidly, that "Every card which has a B on one side has a 3 on the other side" and go on to give the same first-order matching response: 'B and 3'.

Where there are two internal negatives, the external negative appears to lose its cancelling function, and higher-order matching is used to deal with the internal negation. In the previous experiments negation was more

closely associated with the negated item, (ie; 'not B' and 'not 3'). Hence subjects are more likely to understand the negations to modify the associated items rather than to cancel another negative, and higher-order matching is common even on the singly negated variants. Only in the case of the doubly negated variant in the present experiment is higher-order matching the more frequently observed form (see Table 8.3). While it is plausible that two negatives can yield a positive, three negatives are more likely to be seen as continuing to yield negation rather than cancelling one another. The external negative could be thought to cancel one of the internal negatives, but there would be no way of deciding which. Hence the two internal negatives may be more easily taken to modify the content items which, being binary, are easily converted to their positive alternatives, leading to a higher-order matching response.

This explanation is inevitably 'post hoc', in addition to being very speculative. However, the cases compared differ so little in their wording that there appears to be no other independent variable on which to base an alternative explanation. Although the way in which the problem formulations affect responses may not be precisely as suggested, the features of those formulations which are responsible for the effect appear to have been identified by the elimination of other possibilities, and by consideration of the effect of the wording on responses to the problems.

Discussion of an apparently similar effect

There is an interesting similarity between the effects of the number of negated items in the present experiment and the findings of Roberge (1974, 1976a, 1976b, 1978) using disjunctive reasoning tasks. Roberge used problems involving exclusive disjunction such as " 'Either there is a P or there is a Q, but not both', 'There is not a P', 'therefore ...' ". He found that while there were fewest errors on the positive rule (p or q)

quoted above, singly negated disjunctions ('p or not-q', 'not-p or q') elicited almost twice as many errors as the doubly negated variant 'not-p or not-q'.

Evans (1982) ofered two "simple" interpretations of these results. The first of these is that a disjunction with one negative is linguistically unnatural and leads to interpretational confusion and high error rates. This seems implausible on two grounds. First, there were no less than three spontaneously produced responses of precisely the form which Evans declares to be 'linguistically unnatural': 'not-p or q', in Experiment 5 above. Second, to say 'Either he has not yet arrived or he has already left' seems as natural as 'Either he has not yet arrived or he has not waited for us'. Evans's second "simple" interpretation is that "the double-negative disjunctive tends to be converted into an affirmative form. That is, the subject given 'Either not p or not q' drops the negatives, and treats it as though it were 'Either p or q'". He points out that where, as in Roberge's experiments, the disjunction is stated to be exclusive, these two formulations are logically equivalent and dropping the negatives can lead to correct solutions. However, this equivalence does not obtain on inclusive versions of the task (or on singly negated disjunctions). Hence dropping the negatives leads to error in these cases, and superior performance on the doubly negated inclusive variant is not observed.

An interpretation which Evans does not consider is that subjects take p and q to represent the complete set of possibilities (in Roberge's studies each disjunct concerns the presence or absence of an upper case letter), and convert negated disjuncts to their positive alternatives. Hence 'not-p or not-q' would be converted to 'q or p'. This is logically equivalent to the 'p or q' produced by simply dropping the negatives. The way in which this transformation is here suggested to occur is similar to

the first stage of higher-order matching, and on the doubly negated form it would lead to correct responses. For singly negated disjunctives this process would result in conversion of 'p or not-q' to 'p or p', and of 'not-p or q' to 'q or q'. Here such a conversion is invalid and would lead to errors.

Although part of the present research suggests this alternative explanation of Roberge's data, it would require further experimental work to take it beyond the status of conjecture. However, whether this conjecture or the explanation offered by Evans (1982) is correct, neither appears to assist in explaining performance on the doubly negated conjunctive in Experiment 8, since the responses observed could not have arisen in either of these ways. If subjects attempting the doubly negated conjunctive task had dropped the negatives, or converted the negated conjuncts to assertions of the other conjunct (which seems improbable when one is stated to be a letter and the other a number), this would have led to first-order matching in either case. However, the doubly negated conjunctive variant elicited more higher-order matching, and this is consistent only with conversion of the negated letter to the other letter and the negated number to the other number. If Roberge's results suggest anything relevant to the result of Experiment 8, it is that subjects may be more likely to convert negated items into positive ones when two such items are present. This is possibly because the greater complexity of a statement containing two negatives is more likely to cue subjects to simplify the problem by converting the negated items to positive ones.

GENERAL DISCUSSION OF EXPERIMENTS 1 TO 8

Experiment 8 finally allows the results of Experiment 5 to be explained, and those of Experiments 6 and 7 to be reconciled with the findings of Van Duyne (1974) and Legrenzi (1970). The facilitatory effect

of subjects' own formulations was shown in Experiment 6 to have been largely due to the preference for the 'Not both p and not-q' formulation. This formulation is facilitatory in that it can lead to the correct solution through first-order matching in the special case 'Not both p and q', and through higher-order matching on the negated variants. However, higher-order matching also depends on the closeness of association of the internal negations in the wording with the negated terms, and perhaps also on the separation of the external negation from the remainder of the sentence, since this would explain the larger effect in Experiment 6 than in Experiment 7.

This needs qualification, since higher-order matching tends to persist in the case of the doubly negated conjunctive sentence, however the negation is worded. A possible explanation is that the presence of three negatives in the doubly internally negated '-(-p & -q)' rather than two (as in the singly negated variants) inhibits the tendency to regard the negating terms as modifying each other so as to yield a positive interpretation.

The effect of separating negations from the terms they negate may also be responsible for some of the first-order matching observed on problems with multiple content items such as Manktelow and Evans's (1979) Experiment 2 and its replication by Reich and Ruth (1982). In these experiments negation is always separated from the negated term by a verb; for example, "If I do not eat chips, then I do not drink brown ale". This may have enhanced the first-order matching tendency in these experiments.

In Reich and Ruth (1982), Experiment 2, the interpolation of other words between "not" and the negated term is present in only 2 of the 4 problems used. However, in both problems used in Experiment 1 (Chapter 2)

"not" immediately precedes the negated term. This may account for the relatively greater frequency of higher-order matching in Experiment 1 than that observed in the other studies with which it was compared (see Table 1.4).

The main implication of Experiment 1 is that the so-called 'verification responses' which have frequently been observed are apparently due to higher-order matching. It was shown that this form of matching is more frequent when content items are binary, and that with overtly multiple content items first-order matching predominates. This effect of content is most pronounced in the selection of consequent cards because many subjects tend to select the TA card even when the conditional has a negated antecedent and the problem has multiple content items. This feature of antecedent choice was attributed to directional bias which increases the salience of modus ponens inferences as a result of the the 'If, then' wording. There is therefore a stronger tendency for subjects to select a card which corresponds with the whole antecedent, including any negation. When the stage of selecting a card is reached (by contrast with the stage of comprehending the conditional) the choice is always binary as there are only two antecedent cards in the array. For example, in Reich and Ruth's (1982) Experiment 1 on conditionals with a negated antecedent, there were 33 selections which included a single antecedent card and therefore showed a definite preference for one or other of these selections. In spite of the strongly overt multiple content, 14 of these 33 antecedent card selections were of the TA card. The strong tendency to first-order matching was therefore attributable largely to consequent card selections. The effect of multiple or binary content in Experiment 1 (Chapter 2) was also more clear in the case of consequent card selections, as described in the discussion of Experiment 6.

Experiments 2 and 3 investigated whether the production of responses on a non-logical basis (eg; on the basis of matching) is a fall-back strategy which will be observed only when the logical difficulty of the task is beyond subjects' abilities. In Experiment 3 it was shown that all subjects responded on the basis of a salient premise in the falling leaves problem. This occurred even though it was highly probable that some of the subjects were capable of solving the logical problem when the salient premise was absent as in Experiment 2, and therefore of realizing that the salient premise contradicted the other premises. It was therefore concluded that pragmatic response strategies may be used even though subjects are capable of using a logical strategy. Detailed theoretical reasons have been advanced for accepting that non-logical strategies are cued as a part of the process of comprehension or representation of premises. In particular it was argued that the difference in performance on the conditional and disjunctive selection tasks requires such an explanation. Hence it appears that matching bias is initiated before the logical task can be attempted, and that it forestalls such an attempt. Experiment 3, although not directly evidential with respect to matching bias, can be regarded as illustrating this forestalling of logical processing by a salient pragmatic feature of a problem. This was compared with the effect on MP inferences of Byrne's (1986) highly salient but logically irrelevant extra premise: "If she goes out, then she will get wet".

Since it was argued that pragmatic judgements originate as part of the process of comprehension, it remained to be demonstrated that comprehension can take place on the basis of the pragmatic features of sentences without subjects' becoming aware of the effect of their syntactic form on their meaning. Such a conclusion was suggested by the result of Experiment 4, in which subjects rated a sentence as very clear and accurate although consideration of its syntactic structure would have

led to the opposite conclusion. When relational sentences such as conditionals are comprehended in this way, there is no structure to which rules of logical inference can apply. However, inferences can be made on the basis of the sentences' semantic content and pragmatic force (ie; by truth-functional reasoning and the manipulation of mental models). Such inferences will be valid if the processing is correctly carried out to completion. Whether subjects are capable of this will depend on the content of the problem and the demands of the task, such as the number of models required to represent a syllogism (Johnson-Laird, 1983).

If the premises include familiar relations between realistic content items, then reasoning may well proceed on the basis of pragmatically based inferences. Whether this results in logically correct responses will depend on whether the pragmatic aspects of the premises are congruent with their logical aspects. For example, the permission schema underlying the Sears problem is congruent with the syntactic force of the conditional premise, while the fruit-picking problem in Experiment 1 appears to cue an incongruent relevance-based pragmatic judgement which yields matching responses.

This raises the question as to whether the pragmatic and logical aspects of people's spontaneous utterances tend to be congruent. It may appear at first sight that such congruence is essential for effective communication, since otherwise the recipients of a communication might tend to draw conclusions which the communicator did not intend and would hold to be false. However, if both speakers and hearers attend only to the pragmatic force of utterances, most difficulties will be avoided. For example, "No head injury is too trivial to be ignored" appears to convey the intended message in spite of the fact that its syntactic force (ie; its meaning as determined by consideration of its syntactic structure) is incongruent with the intended meaning. In order to notice the

incongruence one has to be aware of the syntactic form of the sentence. However, where relational information concerns an unfamiliar topic, as in the abstract selection task, there is no pragmatically based expectation as to what is intended. The only possible pragmatic judgement is one concerning the relevance of the content items. It is therefore possible that competent speakers will tend to formulate such information in such a way that these relevance judgements will accord with the logical properties of the relation.

In Experiment 5 a conditional relation was presented as a truth-table in terms of acceptable pairs of cards. Subjects most frequently expressed this relation in the form 'Not both p and not-q'. This formulation is such as to produce correct responses when used with binary content in the selection task, since it leads to responses made on the basis of higher-order matching which coincide with the logically correct responses. This would account for the fact that in Experiment 5 subjects made significantly more correct responses to selection tasks formulated in their own words, which were predominantly of the form '-(p & -q)'.

In Experiment 6 other subjects performed significantly better on the '-(p & -q)' formulations than on the 'p -> q' formulations. It therefore appears that speakers may spontaneously formulate their utterances in ways which aid comprehension. Speakers may anticipate the probable pragmatic inferences of hearers, and modify their utterances accordingly.

Experiments 7 & 8 were designed to investigate why Van Duyne (1974) and Legrenzi (1970) did not observe facilitation with the '-(p & -q)' formulations. The results of Experiment 8 suggested that when negation is separated from the negated item as in the formulations of these experimenters, and when there is a single negated item as in the experimental conditions employed by them, then the facilitation is lost

because, with the conjunctive formulation, higher-order matching is largely replaced by first-order matching. In other words, at larger separations between the negating term and the negated item a different pragmatic judgement is made. It is still a relevance judgement, but one which ignores the more distant negating term, possibly because it is regarded as cancelled by the external negation to yield a first-order matching response. This effect is not observed on the doubly negated variant, which suggests that the external negation is not easily regarded as cancelling two internal negatives.

The case against verification bias

While discussing the combined effects of biases, in Chapter 1, it was remarked that many researchers continue to interpret performance on the selection task in terms of verification bias. Continued acceptance of the verification hypothesis supports continued acceptance of the doctrine of mental logic, since verification is based on the use of logical rules which can show that a statement is true. It has been argued that the effect of multiple content casts serious doubt on the verification hypothesis, since it seems implausible that the presence of more alternative content items would cause subjects to abandon the use of a verification strategy. So called 'verification responses' are more plausibly regarded as higher-order matching responses, which tend to be replaced by first-order matching when multiple content items are included in the task. This occurs because it is more difficult to convert a negated item to a positive one when there is more than one positive alternative.

It is possible to argue against this, albeit post hoc, by insisting that what have been described as higher-order matching responses are really due to verification bias; and that the additional complexity of

multiple content causes loss of the insight required for the use of a verification strategy. However, the case against verification bias is further strengthened by the results of Experiment 8. In that experiment it was observed that there was much more first-order matching on the conditional problems when the negating term was at some distance from the item negated. Table 8.4 shows the incidence of first-order matching in Experiment 8 and in other experiments using conditional problems with negatives which immediately preceded the negated item. It seems unlikely that this slight reformulation of the problems could lead to the loss of insight required for the use of a verification strategy, resulting in first-order matching. Furthermore, in the case of the conjunctive problems the higher-order matching responses, when regarded as the result of a logical strategy, amount to responses based on falsification. Higher-order matching yields correct solutions to these conjunctive problems. In other words, it would be necessary to argue that different types of logical strategy are cued by different formulations of the problem, and that the insight necessary for either of them is lost when the negative is relocated. Then one would have to say that, in the case of the conjunctive problems, the logical insight required for falsification is regained when there are two internal negatives. Thus, in order to interpret the results of Experiment 8 in terms of verification bias the verification hypothesis requires so much post hoc modification that it ceases to be tenable. This conclusion is further justified by the evidence in favour of the hypothesis that subjects tend to simplify the problem by converting negated items to positive ones when this is easily done, and when the abundance of negatives more strongly motivates such simplification. This explanation is also supported by the observation in Experiment 5 that subjects tend to minimize the number of negatives in formulating similar relations in their own words.

CHAPTER 6

The THOG Problem

The aim of the present chapter is to consider whether the processes implicated in responses to the selection task are also involved in the generation of patterns of response to the THOG problem. Following a discussion of some published evidence concerning this question, two experiments of my own will be described. The first of these concerns an attempt to devise a pragmatically facilitatory version of the THOG problem. The second experiment investigates the effect of changing the formulation of the problem in two ways. One of these involves the use of conjunctive wording, which was found to be facilitatory in the selection task. The second involves a change which may make it easier to form a complete representation of the problem structure. It will be recalled that in the selection task some erroneous responses were considered to originate at the representational stage rather than at a later stage when 'logical difficulty' could be important. A similar explanation of erroneous responses to the THOG problem may be possible.

The THOG problem was devised by Wason (1977), and it provides an alternative paradigm on which biases in reasoning can be investigated. The problem, in the standard abstract form currently in general use is as follows:

At the bottom of the page are four designs: BLACK DIAMOND, WHITE DIAMOND, BLACK CIRCLE and WHITE CIRCLE. You are to assume that I have written down one of the colours (black or white) and one of the shapes (diamond or circle). If a figure has either the colour or the shape I

have written down, then it is called a THOG. If a figure has both the colour and the shape I have written down, it is not a THOG. If a figure has neither the colour or shape I have written down, it is not a THOG.

I now tell you that the BLACK DIAMOND is a THOG.

What can you say, if anything, about whether each of the other designs is a THOG?

There follows an illustration of the four shapes, arranged in a vertical column, with a space next to the last three for subjects' answers. Subjects may be asked to use '1' or a tick to indicate that the design is a THOG, '2' or a cross to indicate that it is not a THOG or '3' or a question mark to indicate that there is insufficient information or that they are unable to decide.

Correct solutions to the problem are uncommon. Wason and Brooks (1979, Experiment 1) obtained only 3 correct solutions from 14 subjects and Newstead, Griggs and Warner (1982, Experiments 1 and 2) obtained 4 correct solutions from 30 subjects on the standard abstract version of the problem. The most common form of response to the problem (Wason, 1977; Wason and Brooks, 1979) is the 'mirror image' error or 'Type A intuitive error' (Griggs and Newstead, 1983) in which subjects identify the white diamond and black circle as THOGs while the white circle is deemed not to be a THOG. Another common error is for subjects to say that the white circle is not a THOG, and to be unable to decide about the other two figures; Type B intuitive error (Griggs and Newstead, 1983). Wason and Brooks (1979) were the first to describe these forms of response as 'intuitive errors' which, it will be argued, seem to be attributable to a

form of matching response.

The source of intuitive errors in the THOG problem

Since the black diamond is stated to be a THOG, subjects may tend to identify figures with features in common with it as THOGs and, perhaps with more certainty, to identify figures with nothing in common with it as not being THOGs. Both of these responses would suggest that subjects producing them have no insight into the logical structure of the problem. Although particular shapes and colours are not named in the disjunctive rule, one of each is named in describing the positive example of a THOG: the black diamond. It is therefore predictable that if any matching responses are made, they will be made by matching to these features. Hence the matching hypothesis may be taken to predict the responses described as 'intuitive errors', whatever the logical criteria for a figure's being a THOG.

Griggs and Newstead (1983) tested the matching hypothesis by using versions of the problem with different logical criteria. Matching responses were observed in two of these; NOT-THOG and DENIAL-THOG. The NOT-THOG problem is identical to the THOG problem except that subjects are told that the black diamond is not a THOG. Of the 40 subjects participating, 10 gave Type A responses, the correct response to this problem, and there were 2 Type B responses. The DENIAL-THOG problem uses the following rule: 'If, and only if, a design either does not include the colour that I have written down, or does not include the shape that I have written down, or does not include both the colour and shape I have written down, then it is a THOG'. The correct response is that it is impossible to classify any of the designs. There were 16 intuitive errors from the 35 subjects participating. In both of these experiments intuitive errors were the most frequent responses, thus lending support to the matching

hypothesis which predicts them.

Griggs and Newstead (1983) also investigated performance on the ANTI-THOG and NOT-ANTI-THOG problems. In the ANTI-THOG problem subjects were told: 'There is a particular colour and a particular shape such that any of the four designs which has both of them, or neither of them, is called a THOG. If the black diamond is a THOG, could any of the other designs be a THOG?'. The NOT-ANTI-THOG problem is similar except that subjects are told that the black diamond is not a THOG.

Griggs and Newstead (1983) observed 9/20 correct answers (which are the same as the correct answers to the THOG problem) on the ANTI-THOG problem. Incorrect responses were varied. The matching hypothesis would have predicted a tendency to respond with the same intuitive errors as are observed on the THOG problem. However, ANTI-THOG is an easier problem because the rule is formulated in a conjunctive manner rather than a disjunctive one. Thus the relevant rule can be redescribed as saying that figures with the particular shape and the particular colour are THOGs and figures with neither are THOGs. The word 'or' in the ANTI-THOG rule therefore has little semantic or pragmatic force. In addition, the consequences of the description in the ANTI THOG problem are immediately apparent. Since a THOG contains both or neither of the features concerned, two THOGS will have no feature in common. Hence this conjunctive version of the THOG problem, like the disjunctive version of the selection task mentioned previously (Wason and Johnson-Laird, 1969), appears to be so linguistically simple that subjects are not likely to adopt a matching strategy. Instead they may be reasoning truth-functionally and making the appropriate direct inference, rather than making the kind of relevance judgement which leads to a matching response.

On the NOT-ANTI-THOG problem, where the correct response is the same as a Type A intuitive error on the THOG problem, the matching hypothesis would predict a tendency to give the correct response. Only 2 responses of this kind were observed, and in 8 of the 18 erroneous responses subjects stated that there was insufficient information to decide about any of the figures. It has been argued throughout this thesis that matching is not merely a response to bafflement and logical confusion. Only if an alternative to that account of matching is accepted does an explanation become possible as to why so few matching responses are elicited by the NOT-ANTI-THOG problem: a particularly difficult problem on the evidence of only 2/20 correct solutions. It is argued throughout this thesis that matching is not a product of bafflement, but a product of normal linguistic processing. It was suggested that the account of Evans (1983a, 1983b) is correct (see pages 14 & 15): matching results from making relevance judgements. However, in a departure from the account given by Evans, it has also been argued that subject sometimes take factors such as negation into account in making relevance judgements; hence the phenomenon of higher-order matching. On other words, subject do not simply make judgements of what is relevant, but also make judgements as to how those items are relevant (eg; negated items may point to the relevance of their positive alternatives). Using this conception of matching it becomes apparent that subjects attempting the NOT-ANTI-THOG problem might find it difficult to see how the information that 'the black diamond is not a THOG' relates to the conjunctive rule in the problem. This difficulty can arise because there are three ways in which a conjunctive relation (eg; 'p & q') can be false (ie; '-p & q', 'p & -q' and '-p & -q'), but only one way 'p & q' in which it can be true.

In two of these three ways the black diamond can fail to be a THOG. Hence subjects may be unable to make any relevance judgement based on the fact that the black diamond is not a THOG, since it is not possible to decide which of these two possibilities is instantiated by this

information. They may therefore be cued to respond that there is insufficient information to decide whether the other three figures are THOGs: the most frequently observed response to this problem. Hence, somewhat paradoxically in the context of the 'logical difficulty' view of matching, the problem may be too difficult to elicit matching responses. This possibility can arise only if matching responses are regarded, as argued throughout this thesis, as the product of normal linguistic processing and not merely responses to bafflement and logical confusion.

Griggs and Newstead also used the above experiments to evaluate the alternative hypothesis that intuitive errors are due to what Bruner et al (1956) call the 'common element fallacy': the presupposition that positive instances of a concept must have features in common. According to this hypothesis, subjects make the assumption that a THOG must have at least one feature in common with the black diamond, and reason logically thereafter. This hypothesis entails different predictions from those of the matching hypothesis only if matching bias is supposed to occur by 'perceptual matching' to the features of the positive example. Griggs and Newstead (1983) adopt a perceptual view of matching rather than the linguistic account presented in this thesis. This explains their inability to account for the absence of matching bias on the NOT-ANTI-THOG problem, since the linguistically based explanation suggested above is not available to them. When a linguistic account of matching is applied to the THOG problem, it would seem that subjects reach a pragmatically based understanding of the problem which includes a judgement that the features of the black diamond are relevant in deciding whether something is, or is not, a THOG. Classifying the figures on the basis of whether they match one of these features would result in responses which are indistinguishable from those which have been attributed to the common element fallacy.

Evans (1982, p.207) takes a view of the common element fallacy which is similar to the explanation proposed above, and considers it to be "... akin to matching bias". Evans (1983, p.158) also points out that a perceptual explanation of matching bias (such as that adopted by Griggs and Newstead (1983)) is hard to reconcile with its dependence on conditional rather than disjunctive rules in the selection task, and (ibid, p.159) its occurrence when truth-tables are to be evaluted or positive examples constructed. The previously described effects of negatives in the context of binary or multiple content in the selection task also militate against a perceptual explanation of matching bias. The effect concerned illustrates that matching is not simply perceptual but is sensitive to context, since when the same stimuli are presented in binary rather than multiple guise first-order matching is considerably reduced. True, it is replaced by higher-order matching, but this involves a linguistic conversion of the item and is not therefore a perceptual phenomenon. When matching bias is regarded as a linguistically penetrable phenomenon, it appears to be the more acceptable explanation of intuitive errors in the THOG problem.

The explanation of performance on the THOG problem as the result of subjects' susceptibility to the common element fallacy, when this is regarded as a psychologically real logical fallacy, has a parallel in the selection task research, where responses due to (higher-order where possible) matching have been attributed to a 'verification fallacy'. Such explanations unnecessarily introduce considerations of the presence of or absence of 'logical insight'. They are at a level appropriate to evaluation of the cognitive processes concerned ('fallacy' is a term of negative evaluation), rather than at the lower level appropriate to description of these processes. Explanation in terms of matching bias therefore has greater psychological reality and is also preferable by the criterion of Occam's razor, since it avoids invoking the extra (and

somewhat indefinite) variable 'logical insight'.

It has been argued in previous chapters that matching tends to occur when subjects are unable to form a complete structured representation of the premises of a problem. Opinion is divided as to whether this is the case for subjects attempting the THOG problem. Wason and Brooks (1979) found that 71% of subjects in two experiments correctly stated the two possible combinations of a colour and a shape which could have been written down: the 'alternative hypotheses'. However, subsequent completion of the problem did not indicate any facilitation as a result of this. Wason and Brooks concluded that subjects understood the premises, but were not thereby cued to, or were unable to, perform the required combinatorial analysis. More recently Smyth and Clark (1986) reached a similar conclusion using a 'realistic' version of the problem. By contrast Griggs and Newstead (1982), argue that subjects' understanding of the problem is not complete, since their representation of the problem does not include the items not written down and the relation of these items to the items which are written down. Their experiments will be described in the context of Experiment 10 and an attempt will also be made to reconcile these apparently conflicting accounts.

The effect of realistic content in the THOG problem

There have been several attempts to devise facilitatory versions of the task. One approach to this is to use realistic content, as in the selection task. Facilitation produced in this way has been attributed to memory-cuing (Newstead et al., 1982) when the content is very realistic and the correct response is in accordance with experience. Hence when a version of the problem was used which required subjects to choose between 'a hamburger and syrup', 'pancakes and mustard' and 'a hamburger and

mustard' as combinations which the experimenter would eat, and the correct answer was that he would eat only 'a hamburger and mustard', even [redacted] and 9-year-old children showed excellent performance (75% correct). However, on another version of the problem for which the correct answer is that the experimenter would eat only 'pancakes and mustard' there were no correct answers.

Arbitrary combinations of concrete content items produce little facilitation (Wason, 1977; Newstead et al., 1982: Experiment 1). If the conclusions concerning the source of facilitation in the selection task are to be seen to apply to a wider range of reasoning paradigms, it would be desirable to discover whether a version of the THOG problem can be devised which, through the inclusion of plausible content, can facilitate performance in a manner analogous to the Sears problem version of the selection task. This task is made more difficult by the fact that people tend not to use disjunctive descriptions. Familiar examples of such descriptions are therefore predictably difficult to find. This problem may be circumvented by couching a version of the THOG problem in prescriptive terms. Such prescriptive formulations are common to all of the reliably highly facilitatory versions of the selection task which have been described in the literature. Disjunctive prescriptions, as opposed to descriptions, are commonplace (eg; "You may have coffee or tea"), hence this might appear to be the direction in which a search for a facilitatory THOG could most profitably be pursued. The experiment which follows represents one attempt along these lines.

EXPERIMENT 9

In an unpublished study the present author (Turner, 1982) obtained some facilitation using versions of the problem which incorporated familiar relations between the content items in the THOG problem. One such version

of the problem, termed the CARDS problem, appeared to be highly facilitatory, but Griggs (personal communication) found no significant facilitation with this version of the problem during pilot studies. Since the experiment conducted by Turner (1982) involved individual subjects who were known to the experimenter, it was suspected that some of the facilitation might have been due to an experimenter effect. It was therefore decided to investigate whether the CARDS problem would produce facilitation when subjects participated in groups rather than individually as in the earlier study, and the experimenter had no previous acquaintance with the subjects.

In the CARDS problem the content items stand in a relation to one another which may be familiar to subjects. The relation of exclusive disjunction with which the THOG problem is concerned is represented in the CARDS problem as obtaining between the shapes and parities of playing cards. The disjunctive rule is not explicitly stated since it is to be derived by subjects from information contained in the problem (see below under 'Materials'), from which it follows that an acceptable combination must contain either the point-scoring colour or the point-scoring parity, but not both. This relation is isomorphic with the relation obtaining between the written down colour and the written down shape in the standard THOG problem.

METHOD

Subjects

Thirty Keele University students participated on a voluntary basis.

Materials

Each subject was presented with two printed sheets, one with the standard THOG problem and one with the CARDS problem as follows:

A certain card game is played using only the numbered cards in the pack and not the face cards. In order to win you have to get a total score of exactly one point. The game is played by picking a card from the face-down pack. The card scores one point or none depending on its colour and one point or none depending on whether its number is odd or even.

I now tell you that a card which is red and odd wins.

What can you say, if anything, about the other three combinations? Please indicate in the spaces below whether each combination:

(1) wins

(2) does not win

(3) there is insufficient information given to decide on whether it wins or not.

Use 1, 2 and 3 to indicate your answers.

COMBINATION	
Red and Odd	1
Red and Even	_____
Black and Odd	_____
Black and Even	_____

Design and Procedure

Subjects participated in small groups of between 5 and 8 members. Each subject attempted both problems, which were presented in a counterbalanced order. Half of the subjects did the THOG problem first and the other half did the CARDS problem first. Subjects were allowed as long as they required to complete the task.

RESULTS

Of the 30 subjects, 1 gave the correct response to both problems and

4 solved only the CARDS problem correctly. This difference falls just short of significance using a one-tailed sign test ($p = 0.063$).

However, Griggs (personal communication) ran an experiment using the CARDS problem which was identical to the present experiment except that the CARDS problem was always presented first, and the word 'colour' was spelled 'color', the subjects being 24 University of Florida students. The results were the same as those of the present experiment, with 1 subject responding correctly to both problems and 4 correct solution on the CARDS problem only. Therefore a one-tailed sign test again yields a significance of $p = 0.063$.

Using Rosenthal's (1978) formula for combining probabilities from independent studies:

$$p = (p1 + p2 + \ldots)^N / N!$$

$$p = (0.063 + 0.063)^2 / 2$$

$$p = 0.126^2 / 2$$

$$p = 0.008$$

Hence the combined result is significant at the $p < 0.01$ level. It seems unlikely that Griggs's experiment could have been affected by the fixed order of presentation, since in the present experiment, of the four subjects who responded correctly to the CARDS problem, two did the THOG problem first and two did it second. Hence it might appear that a small but reliable degree of facilitation has been observed on the CARDS problem through the use of a familiar arithmetical relation which is isomorphic with the relation of exclusive disjunction in the THOG problem. The smallness of the degree of facilitation may be due to the fact that although the relation concerned is a familiar one, the context in which it is presented is that of an arbitrary rule. It therefore remains a

possibility that if such a relation were incorporated into a more realistic and sensible rule, as for example in the Sears version of the selection task, a greater degree of facilitation might be observed.

On the other hand, it may be that the CARDS problem is facilitatory, not because it includes a familiar relation, but because the relation of exclusive disjunction is not formally stated in the problem. Smyth and Clark (1986) argue that a formal statement of the disjunctive rule gives subjects the impression that the problem is insoluble because of the presence of two unknowns. They take the widely held view (which is challenged in this thesis) that the intuitive errors observed are the result of a form of matching which is induced by logical difficulty. The logical difficulty, according to Smyth and Clark (1986), consists in the apparent insolubility of the problem when subjects form the impression that it involves two unknowns.

They used a problem which involved "being my half-sister", which they defined disjunctively as "If and only if the description of a woman's parents includes either the mother I have written down or the father I have written down, but not both, then that woman is my half-sister". They asked subjects to consider the four possible pairings between 'my father', 'my mother', 'George' and 'Jane': given that the parents of one half-sister are 'my father and Jane'. When the disjunctive definition was not included in the instructions, 14 out of 15 subjects correctly responded that only 'my mother and George' could also be parents of 'my half-sister'. When the disjunctive definition was included in the instructions there were only 11 out of 30 correct responses. The central problem is much simpler than the THOG problem since it can be solved even without a positive example. The fact that 'my mother' and 'my father' are included in the list of people, instead of the names of another woman and man, removes the possibility of considering alternative hypotheses as to

which of the parents of a particular half-sister is also one of my parents. When the terms 'my mother' and 'my father' were replaced by 'Mary' and 'Tom', and the disjunctive definition was included, performance was no better than on the standard THOG problem.

As noted above, Smyth and Clark (1986) concluded that, on the first version of the problem, using the terms 'my mother' and 'my father', the presence of the disjunctive rule suggested to subjects that there were two unknowns in the problem, and that it was therefore insoluble. They argue that in the standard THOG problem the disjunctive rule has the same effect: subjects decide that the problem is insoluble and are therefore deterred from testing the alternative hypotheses. Smyth and Clark (1986), using the harder version of their half-sisters problem which lists only two male and two female names, asked subjects to state the alternative hypotheses; in this case the pairs who could be 'my parents'. They found that 20/30 subjects were able to list the correct pairs, but only 3 of these 20 subjects went on to give a correct answer to the problem. This is comparable with the observations of Wason and Brooks (1979) who found that 9/14 subects could state the alternative hypotheses in the THOG problem, but only 3 went on to give correct solutions. Both Wason and Brooks (1978) and Smyth and Clark (1986) argue that the difficulty of the problem is a computational one and subjects do not attempt, or cannot perform, the combinatorial analysis required to test the alternative hypotheses as to what the 'written-down' features might be. This view seems to be contradicted by the fact that Smyth and Clark's subjects perfomed less well when the disjunctive rule was included in the easy version of the half-sisters problem which uses the terms 'my mother' and 'my father', and therefore contains no unknowns and requires no hypothesis testing.

In the case of the THOG problem, the argument rests on the assumption

that combinatorial analysis and hypothesis testing are required in order to solve the problem. However, it may also be solved by representing the relation involved as a conjunctive one. Complete comprehension of the premises of the THOG problem could result in a representaton which includes the set of two written down features and the set of two features which are not written down.

Written Down	Not Written Down
colour	shape
shape	colour

From the fact that a THOG must combine a colour and a shape, and only one of these must be from the 'written down' list, the following elaboration of the representation may occur:

Written Down		Not Written Down		
colour	+	shape	=	THOG
shape	+	colour	=	THOG

Such a representation of the premises of the problem might enable subjects to see that when 'black' and 'diamond' are substituted for one of the THOG-making combinations, only 'white' and 'circle' remain to form the other allowable combination. It is therefore possible that the presence of the disjunctive rule (contrary to the view of Smyth and Clark, 1986) actually encourages hypothesis testing: a strategy which subjects appear to find difficult to execute correctly.

The easy version of the half-sisters problem (Smyth and Clark, 1986) illustrates more clearly than the THOG problem how subjects might represent the relation involved as a conjunctive one. The parents of a

half-sister must be 'one of my parents and a person who is not one of my parents'. The presence of the disjunctive and asymmetrical definition of a half-sister may prevent some subjects from understanding and representing the relation as a conjunctive one. This would explain why subjects fare worse on this problem, which does not require hypothesis testing, when the disjunctive rule is included. The formal statement of the rule may cue a strategy which is not the optimal one; not only for this easier problem, but also for the standard THOG problem if subjects who solve it tend to do so in the manner described above.

A way of investigating whether subjects do, in fact, reason in the way outlined above is suggested by the experiments of Griggs and Newstead (1982). They pointed out that the features which are not written down, although implicit in any formulation of the problem, are not named or defined in the versions of the task usually presented to subjects. They suggested that this asymmetrical formulation of the problem is part of its difficulty. It is precisely in the formal statement of the rule that the asymmetrical presentation is most apparent. It is also in this formal statement that the disjunctive relations between the elements of the problem are emphasized, at the expense of the conjunctive ones. The disjunctive and asymmetrical wording may cue subjects to attempt the problem by forming alternative hypotheses; only to find that they are unable to decide between the alternatives. It will be recalled that subjects who generate the appropriate hypotheses, when instructed to do so, do not produce more correct solutions. If subjects who solve the problem correctly do so by first generating such hypotheses, then this finding is difficult to explain. On the other hand, if subjects who spontaneously solve the problem do so by following the conjunctive solution-path suggested above, then an instruction to generate the hypotheses would inhibit correct solutions, as may the disjunctive and asymmetrical wording of the problem. Such features of the problem's

presentation may cue the logically valid but demanding hypothesis-testing strategy at the expense of the conjunctive solution-strategy which subjects might be more inclined to adopt and better able to follow.

If these considerations are brought to bear on the results of Experiment 9, the possibility arises that subjects do better on the CARDS problem than on the THOG problem because they represent the relation between the cards in the conjunctive form suggested above. They are not cued to think mainly of only one colour and one parity of the cards, nor of the disjunctive relation between them.

A more general objection to the 'combinatorial analysis' account of how subjects sometimes solve the THOG problem correctly is that the idea of a combinatorial analysis system in the mind may be open to the same objections as that of a logic in the mind. With a full representation of a problem, a solution may be reached without the use of logical or combinatorial analysis. It may be that whenever subjects solve the THOG problem correctly, they do so by seeking a solution which is consistent with a representation of the kind described above, in much the same way as Johnson-Laird (1983) has suggested that they solve syllogistic and other types of problems.

Following from these considerations, the next experiment to be described will be concerned with investigating whether subjects perform better when the disjunctive and asymmetrical features of the THOG problem are removed. Removal of these features might cue the kind of representation suggested above, and the derivation of a solution from that representation.

INTRODUCTION

It has been mentioned above that Griggs and Newstead (1982) concluded that the THOG problem is solved more easily when the version of the problem presented to subjects explicitly names and defines both halves of its structure. In the case the standard THOG problem these halves consist of the items which are stated to be written down and the items which are not stated to be written down. In their experiments Griggs and Newstead (1982) used for comparison the standard THOG problem described above, which lacks any explicit mention of the colour and shape which have not been written down. They suggested that this asymmetrical formulation of the problem is a major source of its difficulty, and compared subjects' performance on an abstract version and some thematic versions of the problem (described below) which name and define, with equal emphasis, all of the items involved in the problem. Performance on these latter problems was found to be significantly superior to that on the original asymmetrical THOG problem. They concluded that this symmetrical presentation of the problems was responsible for the facilitation they observed. However, their facilitatory problems differed in other respects from the THOG problem: notably in having conjunctive wording which could have cued subjects to adopt the conjunctive solution-path described above. Hence no unequivocal interpretation of their results is possible. In order to illustrate this point the confounding variables in their experiments will be described.

An examination of the wording used by Griggs and Newstead reveals that in every case in which a symmetrical rule was used and there was superior performance, the rule used was not only symmetrical but was also

expressed in a conjunctive form. The conjunctive nature of the formulations is not immediately apparent. For instance, it may take more than one reading of the following example of Griggs and Newstead's (1982) problems before it is realized that the word 'similarly' has the logical force of 'and', and is the principal logical connective in the problem. In the drug problem (Griggs and Newstead, 1982; Experiment 1) the instruction was, "You must give the patients potassium either in an injection or orally every day, but of course you must not give them both the potassium injection and the potassium pill. Similarly, you must give the patients calcium but not both the calcium injection and the calcium pill". Subjects were shown the following table and told that Answer 1 represented a correct combination.

	Injection	Drug
Answer 1	Deroxin	Prisone
Answer 2	Deroxin	Triblomate
Answer 3	Altanin	Prisone
Answer 4	Altanin	Triblomate

Subjects were asked whether each of the other three answers was correct or not. Clearly they were able to choose only among combinations of an injection and a pill (misleadingly termed "Drug" in the table). The means of administration of the drug is not a variable which subjects need to consider in solving the problem. The instruction can therefore be summarized as "You must give the patients calcium and potassium", since the content of the dose is all that subjects need to consider. Hence the disjunctive phrasing of "either in an injection or orally" is irrelevant to subjects' classification of the combinations of drugs. They merely have to classify combinations of two different drugs as correct, and two similar drugs as incorrect. In other words, the only relevant variable is the content of the drugs.

Not only are symmetrical formulation and conjunctive formulation confounded in the problems used by Griggs and Newstead (1982) but, like the drug problem, the other problems all differ from the THOG problem in having only one variable. The THOG problem has two variables: colour and shape. This difference seems to make the problems easier, and prevents a valid comparison between performance on these problems and the THOG problem. In order to make it apparent that no clear conclusion can be drawn from the results of Griggs and Newstead (1982) it will be necessary to explain why their problems must be regarded as having important differences from the THOG problem: differences of which they were apparently unaware.

Their 'structured abstract problem' is very similar to the drug problem except that its content is more abstract. Griggs and Newstead describe it as follows: "The structured abstract problem required subjects to decide which pairs of nonsense syllables corresponded to 'correct' combinations of objects. Subjects were told that a correct combination must consist of one black and one white object, and that there must be one square and one circle. Squares and circles were given nonsense names, but the problem did not indicate which nonsense name corresponded to a white object and which to a black". In this problem colour and shape may both appear to be variables at first sight, but the four combinations which subjects are asked to classify are all said to contain one square (CHON or THIG) and one circle (GREF or WULP). Hence the only criterion on which a combination can be accepted or rejected is colour. Since two colours can be classified as the same or different, unlike a colour and a shape, the rule asks no more than that pairings of different colours should be accepted, as with the required pairing of different contents in the drug problem. Since there are two items of each colour, and CHON and GREF must be of different colours to be acceptable, it follows rather easily that

THIG and WULP is the other correct combination.
Again there is only one variable in this problem: colour.

The 'structured diet problem' is identical to the diet problem (described below) except that the sandwiches contained either meat or cheese and the ladies were instructed to have meat for one and only one meal, and to have cheese for one and only one meal. In this problem the only variable is the food item, meat or cheese; as in the case of the drug problem the only variable is the content, calcium or potassium. Hence a similar easy route to the solution could be described for these problems as for the structured-abstract problems. It is not possible to analyze the THOG problem in this way, since the content of the instances, combinations of a colour and a shape, precludes applying the description 'different' or 'the same' to the pairs of content items. Hence there is an important semantic difference between Griggs and Newstead's problems and the standard THOG problem.

In their diet problem, unlike their other novel problems, Griggs and Newstead use a disjunctively and asymmetrically worded combinatorial rule, "You must have the two ounces of meat either for lunch or for dinner, but you must not have meat for both lunch and dinner". Subjects were told that two of four numbered sandwich boxes, one contained roast beef sandwiches, one ham sandwiches, one cheese sandwiches and one cucumber sandwiches. They were shown the following table and told that Joan had eaten a correct combination of sandwiches according to the instruction. Once again there is only one relevant variable: the food item, meat or non-meat.

	Lunch Sandwich	Dinner Sandwich
Joan:	From Box 1	From Box 3
Mary:	From Box 1	From Box 4
Helen:	From Box 2	From Box 3
Susan:	From Box 2	From Box 4

The diet problem resulted in 6 out of 21 correct responses when it was presented first, and 13 out of 21 when it followed the drug problem, which had also elicited 13 out of 21 correct responses (Griggs and Newstead, 1982; Experiment 1). In their Experiment 4 the standard THOG problem was presented after the drug problem, but no facilitation was observed. Griggs and Newstead argue that following the drug problem facilitation is obtained only with the diet problem because the diet problem resembles the drug problem more closely than does the THOG problem, thus permitting a transfer effect. They suggest that this is because the diet problem is semistructured, mentioning negatively the non-meat items (cf; the features not written down in the THOG problem). In fact the diet problem mentions exactly as much as does the THOG problem. In the diet problem there are two meat items 'beef' and 'ham', and two non-meat items 'cheese' and 'cucumber', all of which are mentioned. In the THOG problem there are two colours 'black' and 'white', and two shapes 'diamond' and 'circle', all of which are mentioned. In the diet problem the rule is given in terms of the meat items alone, no mention being made of the non-meat items. Analogously, the THOG problem rule is presented solely in terms of the shape and colour which have been written down, no mention being made of those which have not been written down.

Hence Griggs and Newstead's explanation of the difference in transfer effect to the diet problem and the THOG problem following the drug problem does not appear to be soundly based. On the other hand, the drug problem

and diet problem are similar, since they are both 'one variable' problems: it is possible to say that a combination of meat and non-meat is a combination of 'different' items. The THOG problem is however a two variable problem: a combination of black and diamond is no more or less 'different' than a combination of black and circle etc. Hence the main respect in which the drug and diet problems are similar, and unlike the THOG problem, is in the number of variables involved. It is apparently this feature which permits the transfer effect to occur.

It follows from the preceding remarks that, as suggested previously, it is not possible to conclude whether superior performance on the problems reported in Griggs and Newstead (1982) is attributable to symmetrical presentation, conjunctive wording, the presence of a single variable or some combination of these features. Indeed, the confounding with conjunctive wording is particularly suspect, since it has been established experimentally (Griggs and Newstead, 1983: Experiment 2) that conjunctive wording alone, as in the ANTI-THOG problem, where a THOG is defined as having both or neither of the written-down colour and shape, can elicit 45% of correct responses. It has also been pointed out that there is a possible conjunctive solution-path (see page 145) which subjects might use spontaneously in solving the problem. If such a solution can occur spontaneously, then it seems likely that conjunctive wording would cue more subjects to solve the problem in this way.

The present experiment was designed to examine the effects of symmetry and conjunctive wording on the THOG problem. The problems used had two variables, and involved four kinds of presentation of the problem: symmetrical conjunctive, symmetrical disjunctive, asymmetrical conjunctive and asymmetrical disjunctive.

METHOD

Design

Subjects were each presented with one of the four kinds of problem named above. Hence comparisons of performance were between subjects.

Subjects

Eighty-nine undergraduates studying psychology at Keele University participated on a voluntary basis. They took part as three groups of approximately equal size.

Materials

The problems were presented on printed sheets. Each subject received a printed problem sheet showing the four designs at the bottom. Each sheet contained the following wording:

"At the bottom of the page are four designs: BLACK DIAMOND, WHITE DIAMOND, BLACK CIRCLE and WHITE CIRCLE. You are to assume that I have written down the name of one of the colours (black or white) and one of the shapes (diamond or circle) on one piece of paper, and typed the name of the other colour and the other shape on a second piece of paper".

There followed one of the four rules described below; and the wording continued:

"I now tell you that the BLACK DIAMOND is a THOG.
What can you say, if anything, about whether each of the other three designs is a THOG?

"Please write your answers in the spaces below by putting:

a tick "√", if it is a THOG

a cross "x", if it is not a THOG

a question mark "?", if you cannot say whether or not it is a THOG".

The four rules were as follows:

Symmetrical conjunctive problem (SC)

"If a design has both the colour I have written down and the shape I have typed, then it is called a THOG. If a design has both the colour I have typed and the shape I have written down, then it is called a THOG.

If a design has both the colour I have written down and the shape I have written down, it is not a THOG. If a design has both the colour I have typed and the shape I have typed, it is not a THOG.

Asymmetrical conjunctive problem (AC)

"If a design has the colour I have written down but not the shape I have written down, then it is called a THOG. If a design has the shape I have written down but not the colour I have written down, then it is called a THOG.

If a design has both the colour and the shape I have written down then it is not a THOG. If a design has neither the colour nor the shape I have written down then it is not a THOG".

Symmetrical disjunctive problem (SD)

"If a design has either the colour I have written down or the shape I have typed, then it is called a THOG. If a design has either the colour I have typed or the shape I have written down, then it is called a THOG.

If a design has both the colour I have written down and the shape I have typed, it is not a THOG. If a design has both the colour I have typed and the shape I have written down, it is not a THOG".

Asymmetrical disjunctive problem (AD)

"If a design has either the colour I have written down or the shape I have written down, then it is called a THOG.

If a design has both the colour I have written down and the shape I have written down, it is not a THOG. If a design has neither the colour I have written down nor the shape I have written down, it is not a THOG".

Note that the asymmetrical rules define a THOG only in terms of the features which are written down, and the typed features are not mentioned. The symmetrical rules define a THOG in terms of written-down and typed features. The conjunctive rules define a THOG in terms of whether each of two features must be present or absent (as in the ANTI-THOG problem described near the beginning of this chapter) while the disjunctive rules define a THOG in terms of two features, one or the other (but not both) of which must be present. The features mentioned have been selected in such a way that all four rules are logically equivalent, and therefore the correct response to all four problems is the same. In the asymmetrical disjunctive rule a THOG is defined in the same way as in the standard THOG problem described at the beginning of this chapter.

It is possible that the mention in the preliminary instructions of both the written and typed features may serve to cue the conjunctive solution-path suggested above, thus facilitating performance on all these versions of the problem. Mention of these features was retained in each condition in order not to introduce confounding between mention of typed

and written-down features in the background information and formulation of the rule in terms of these features. This experiment therefore tests the hypothesis that symmetrical and conjunctive rule formulations are facilitatory in a context which includes positive mention of the typed features, rather than one which leaves them to be defined negatively as 'not written down'. This is in contrast to the procedure adopted by Griggs and Newstead (1982) who do not distingish between rule formulation and problem context in the design and discussion of their experiments.

Procedure

Subjects were asked to attempt the problem when they had understood the instructions. They were allowed as much time as they required to complete the problem.

RESULTS AND DISCUSSION

Subjects responses were categorized according to whether they appeared to indicate the use of a correct solution strategy or took the form of one of the two kinds of intuitive error. Correct solutions were naturally included in the former category, as were the responses described as 'near insight' by Wason and Brooks (1979): responses where the white circle is correctly classified as a THOG, but the subject is unable to decide how to classify the other two figures.

TABLE 10.1

Frequency of four response types on four variants of the THOG problem

	Correct	Near Insight	Intuitive Errors	Others
Symmetrical conjunctive	11	1	1	9
Asymmetrical conjunctive	6	2	5	10
Symmetrical disjunctive	7	0	5	10
Asymmetrical disjunctive	3	0	9	10

Inspection of Table 10.1 indicates that the effects of changing the standard (AD) THOG by including symmetrical presentation (SD) or conjunctive wording (AC) were very similar. Both of these modifications resulted in 4 fewer intuitive errors. In addition, the SD problem yielded 4 more correct responses, while the AC problem yielded 3 more correct responses together with 2 responses indicating near insight.

For the purposes of statistical analysis the 3 near insight responses were combined with the numbers of completely correct responses. A chi-squared test indicated that the difference in performance on the two symmetrical problems (SC and SD) compared with the two asymmetrical problems (AC and AD) was significant at the $p < 0.04$ level. Hence the conclusion of Griggs and Newstead (1982) that symmetrical presentation is facilitatory is supported in the case of an abstract THOG problem with two

variables.

Performance on the two conjunctively formulated problems (SC and AC) was significantly different from that on the disjunctively worded problems (SD and AD) at the $p < 0.02$ level. This suggests that the unrecognized inclusion of this variable in the experiments of Griggs and Newstead (1982) contributed to the size of the differences in performance which they observed.

The overall pattern of the results tends to confirm the earlier suggestion that both of these kinds of formulation cue subjects to adopt the conjunctive solution-path described above. It seems highly probable that subjects solve at least the symmetrical conjunctive problem in this way, without any need for combinatorial analysis. If, as other researchers have supposed, correct solutions to the asymmetrical disjunctive standard THOG problem are reached by combinatorial analysis, then on the intermediate SD and AC problems some conflict should occur. Neither of the alternative solution-paths would be clearly cued by these intermediate problems. Hence performance on these problems ought not to improve so much over performance on the standard THOG problem, and might even become worse due to the lack of a clear cue towards a particular solution-path. In fact, there were 4 fewer intuitive errors on each of the intermediate problems than on the AC problem, and 4 fewer again on the SC problem. Correct, or near correct, solutions increased by 4 and 5 on the intermediate problems (SD and AC), and by a further 5 and 4 on the SC problem. The cumulative and almost equal effects of symmetrical and conjunctive presentation might suggest that both of these modifications of the problem cue the same solution strategy; and that the strategy concerned is, at least, one towards which subjects are not disinclined when presented with the standard THOG problem. It seems that both conjunctive and symmetrical presentation may elicit a fuller

representation of what then amounts to a problem concerning a conjunctive relation. Hence features, such as symmetrical presentation, which can assist in representation may also make it easier to derive a solution from that representation using the conjunctive solution-path.

On a more general note, it appears that as a consequence of thinking about the THOG problem in terms of the application of mental logic, researchers have been led to believe that it requires hypothetico-deductive reasoning using combinatorial analysis. It has not been appreciated that an adequate mental model may be sufficient to allow a solution to be reached on the basis of the conjunctive relations which such a model must include. Subjects need not consciously reformulate the problem in conjunctive terms (although such reformulation by the experimenter appears to help). The conjunctive relation between the features of a THOG is a logical property of such a model; but it is sufficient merely that subjects be able to perceive which combinations of features the model allows, and which are not permitted. As with the syllogistic and other problems considered by Johnson-Laird (1983), mental logic is not required to solve the THOG problem.

The above considerations may be brought to bear on the apparent difficulty of devising a version of the THOG problem which facilitates performance as a result of realistic and familiar content. In order to avoid the possibility of memory-cuing, the relation must not be a familiar one which is known to obtain between the content items. The use of nonsense words to describe the content should satisfy this memory-cuing constraint. Since the THOG problem can be based on a conjunctive relation and then reformulated in disjunctive and asymmetrical terms, many more possibilities arise than when it was thought that a realistic THOG problem must involve a naturally disjunctive relation, as opposed to a disjunctive verbal formulation. If a sufficiently familiar conjunctive relation is

used, and rediscribed in disjunctive term, this should cue subjects to use the conjunctive solution-path suggested above.

The suggested experiment has yet to be carried out, but here is a suggestion of how it might be done. It would first be necessary to decide upon a familiar conjunctive relation which could be embodied in a task in such a way that the problem would be isomorphic with the THOG problem. A common type of conjunctive relation is that between an animal and the kind of food it eats; 'dog and meat' for example. If the animal is kept in a pen and it is desired to control the amount that it eats, one could make it a rule that the pen should contain either the dog or the store of meat, but not both. This particular rule could not be used in the problem because it contains a memory cue, since most people would recall that dogs eat meat. However, nonsense names may be used for animals and their food to yield a THOG isomorph such as that which follows.

I have two animals, a CHON and a GREF, which I keep in separate pens. One of them eats only WULP and one eats only THIG, but I am not telling you which animal eats which kind of food.

Because of lack of space I have to store the animals' food in their pens; but if I keep an animal with its own kind of food it will eat too much and become ill. I therefore make it a rule that a pen must contain either a particular animal or its own kind of food, but not both together. I now tell you that it is correct, according to my rule, to keep the CHON and the WULP in the same pen. What can you say about whether it is correct to keep the three other combinations listed below in the same pen.

Animal	Food	
CHON	WULP	--- Correct
CHON	THIG	---
GREF	WULP	---
GREF	THIG	---

This problem has two variables: the type of animal and the type of food. The relevant rule is formulated disjunctively, and it is asymmetric since it does not mention the other type of animal or the food appropriate to it. Nor is memory-cuing a possibility. In fact it differs from the THOG problem in only one essential feature: there is a familiar relation involved between an animal and 'its own kind of food'.

Since the experiment has not yet been carried out, it is left to the reader to decide whether this problem appears to invite the construction and testing of alternative hypotheses. There appears to be little basis for such a conclusion, and the problem looks so easy that it might be doubted whether it is isomorphic with the THOG problem. However, it is only necessary to substitute 'design' for 'pen, 'THOG' for a correctly filled pen, 'colour' for 'animal', 'black' and 'white' for 'CHON' and 'GREF', 'shape' for 'food' and 'diamond' and 'circle' for 'WULP' and 'THIG' in order to transform this problem into the THOG problem. The relation between an animal and its own kind of food is logically the same as the relation between the written-down colour and shape in the THOG problem. This problem looks easy simply because there is a familiar relation between an animal and its food which does not obtain between a shape and a colour. This may well be sufficient to cue the optimal conjunctive solution-path described above.

CHAPTER 7

CONCLUSION

In Chapter 1 the question was raised; 'Under what conditions do educated adults fail to give correct responses to formal problems?'. Formal problems are problems to which the solutions depend only on the relations between their content items as determined by the syntactical structure of their premises. Hence in cases where subjects do not form a representation of the premises on the basis of their syntactical form, errors will occur and correct responses will be adventitious. In Experiment 3 it was shown that even when the syntactic structure of the premises is not particularly complex, additional semantic information may prevent syntactically based solutions by making the syntactic information appear irrelevant. In Experiment 4 it was shown that a sentence may be comprehended on the basis of pragmatic factors rather than its syntactic structure. Many of the erroneous responses to the selection task and THOG problem have been attributed to the use of a matching strategy: a pragmatically based heuristic the use of which leads to responses which accord with relevance judgements. It was shown in Experiment 1 that, particularly when content items are perceived as binary, many of the responses previously thought to be a result of a verification strategy are in fact the result higher-order matching.

It appears that the only way to ensure that responses are made on the basis of the syntactic features of a problem is to express the problem in a form which is sufficiently simple to allow truth-functional inferences to be made using semantic composition: what have been referred to as 'direct inferences'. An example of this has been observed when the selection task is expressed as a positive disjunction, in which case the majority of responses are correct and are not attributable to matching

bias. Further examples of this kind of facilitation may be afforded by the prevelance of correct solutions to the ANTI-THOG problem with its conjunctive formulation and the conjunctively and symmetrically formulated versions of the THOG problem in Experiment 10.

Another way to raise the probability of correct responses is to make the pragmatic relations between the content items familiar ones which are isomorphic or congruent with the syntactic relations. Pragmatically based judgements about those relations will then be more salient than judgements concerning the relevance of content items. Hence correct responses based on those relations will be more frequent, as illustrated by performance on the Sears problem, and as hypothesized on the 'animals and food' problem suggested above.

Alternatively the syntactic form of the premises may be manipulated in such a way that the probable relevance judgements correspond to the logically correct responses, and no alternative pragmatic relations between the content items are suggested. For example, the 'Not both p and not-q' formulation of the selection task tends to elicit correct responses because responses made on the basis of a (higher-order) matching strategy coincide with the logically correct responses. The infrequency of correct responses to the NOT-ANTI-THOG problem might appear to constitute an exception to this since matching responses would coincide with the correct responses to this problem. However, it is a principal contention of this thesis that matching bias is a linguistically based bias which is sensitive to sentential context and, in particular, to negation. Hence when subjects are given a negative example, as in the NOT-ANTI-THOG problem (the black diamond is not a THOG) they are unable to decide how it relates to the conjunctive rule. This linguistic penetrability of matching bias lends support to the view that it is a linguistically based bias, and is not a last resort strategy in response to logical bafflement.

Another factor which appears to militate against correct solutions is the unfamiliarity of the syntax used in formulating the selection task and the THOG problem. Formal statements of the rule appear to increase the error rate in the THOG problem (Smyth & Clark, 1986); and subjects in Experiment 5 above gave many more correct responses when they formulated the selection task rule for themselves. In addition, formulations similar to those produced by subjects in Experiment 5 elicited many more correct solutions from other subjects than did the standard formulation of the selection task rule in Experiment 6. This suggests that in everyday linguistic interactions, the participants are principally concerned to communicate in ways which are pragmatically effective. The features of a state-of-affairs which are perceived as salient and relevant to a communicator are likely to be the features mentioned in the communication. Similarly, a communicator is likely to formulate the communication in such a way that its truth-functional implications can immediately be seen. Hence if the recipients of such communications base their understanding on the pragmatic force of the communication, they will be unlikely to misunderstand what the communicator intends. Indeed, the partial redundancy of the syntactic form of a communication means that communications may be understood correctly even if they contain grammatical mistakes. Hence communications containing such mistakes tend to produce awareness of the presence of those mistakes rather than misunderstanding of the intended message.

By undertaking the present research in the spirit of enquiry into the conditions under which errors are made it has been possible to avoid classifying those errors in advance. In particular, there has been little motivation to assume that such errors are 'logical errors' although, in an evaluative sense, they might legitimately be so described. It would appear that commitment to an evaluative approach to human reasoning may

have been responsible for the view that there is a logic in the mind.

The 'mental logic' based presuppositions and conclusions concerning performance on the selection task and the THOG problem have been shown to have little empirical justification. Explanations of performance on the selection task in terms of logical bafflement and verification have been shown to have largely spurious empirical support derived from experiments in which confounding variables tend to be implicated. Using an easier problem, and even turning the task into one of comprehension alone, does not prevent responding on the basis of relevance judgements and pragmatic features of the task. Hence logical bafflement does not appear to be responsible for the similarly based matching responses.

In the case of the THOG problem, the empirical evidence has been shown to favour, once again, an explanation of the commonest responses in terms of a linguistically based matching strategy. The evidence which has a bearing on the psychological reality of the presupposed logical solution strategy suggests that subjects do not reason in this way about the THOG problem. Instructions to list the possible combinations of written-down items have not been facilitatory, and neither has the inclusion of an actual disjunctive relation which obtains between the parents of a person's half-sisters. By contrast, explicit mention of the items which are not written down (the items said to have been 'typed' in Experiment 10) has been facilitatory; yet these items are not involved in the disjunctive relation which is central to the original formulation of the problem. In addition, conjunctive formulation of the problem contributed further facilitation. All of this evidence suggests that the stategy which comes naturally to subjects is the proposed conjunctive solution, based on a representation of the problem in the form of a mental model.

Beth, E.W. and Piaget, J. 1966. Mathematical epistemology and psychology. Dordrecht: Reidel.

Bennett, J. 1976. Linguistic Behaviour. Cambridge University press.

Bracewell, R.J. and Hidi, S.E. 1974. The solution of an inferential problem as a function of the stimulus materials. Quarterly Journal of Experimental Psychology, 26, 480-8.

Brown, C., Keats, J.A., Keats, D.M. and Seggie, I. 1980. Reasoning about implications: a comparison of Malaysian and Australian subjects. Journal of Cross-Cultural Psychology, 11, 395-410.

Bruner, J.S., Goodnow, J.J. and Austin, G.A. 1956. A Study of Thinking. New York: Wiley.

Byrne, R.M. 1986. The effects of contextual information on conditional reasoning. Paper presented at the annual conference of the British Pschological Society, Sheffield University.

Cheng, P.W. and Holyoak, K.S. 1985. Pragmatic reasoning schemas. Cognitive Psychology, 17, 391-416.

Cheng, P.W., Holyoak, K.S., Nisbett, R.E. and Oliver, L.M. 1986. Pragmatic versus syntactic approaches to training deductive reasoning. Cognitive Psychology, 18, 239-328.

Cohen, L.J. 1981. Can human irrationality be experimentally demonstrated?

Behavioural and Brain Sciences, 4, 317-31.

Cox, J.R. and Griggs, R.A. 1982. The effects of experience on performance in Wason's selection task. Memory and Cognition, 10, 496-502.

Evans, J.St.B.T. 1972. Interpretation and 'matching bias' in a reasoning task. Quarterly Journal of Experimental Psychology, 24, 193-9.

Evans, J.St.B.T. 1975. On interpreting reasoning data: a reply to Van Duyne. Cognition, 3, 387-90.

Evans, J.St.B.T. 1977. Linguistic factors in reasoning. Quarterly Journal of Experimental Psychology, 29, 297-306.

Evans, J.St.B.T. 1982 The psychology of deductive reasoning. London: Routledge and Kegan Paul.

Evans, J.St.B.T. (ed) 1983. Thinking and reasoning: psychological approaches. London, Routledge and Kegan Paul.

Evans, J.St.B.T. 1983a. Selective processes in reasoning. IN Evans (1983).

Evans, J.St.B.T. 1983b. Linguistic determinants of bias in conditional reasoning. Quarterly Journal of Experimental Psychology, 35a, 635-44.

Evans, J.St.B.T. and Beck, M.A. 1981. Directionality and temporal factors in conditional reasoning. Current Psychological Research, 1, 111-20.

Evans, J.St.B.T. and Lynch, J.S. 1973. Matching bias in the selection task. British Journal of Psychology, 64, 391-7.

Evans, J.St.B.T. and Newstead, S.E. 1977. Language and reasoning: a study of temporal factors. Cognition, 8, 265-83.

Gilhooly, K.J. and Falconer, W.A.. 1974. Concrete and abstract terms and relations in testing a rule. Quarterly Journal of Experimental Psychology, Quarterly Journal of Experimental Psychology, 26, 355-9.

Golding, E. 1981. The effect of past experience on problem solving. Paper presented at the Annual Conference of the British Psychological Society, Surrey University.

Greene, J. 1970. The semantic function of negatives and passives. British Journal of Psychology, 61, 17-22.

Greenwald, A.G., Prakatnis, A.R., Leippe, M.R. and Baumgardner, M.H. 1986. Under what conditions does theory obstruct research progress? Psychological Review, 93, 216-29.

Griggs, R.A. 1983. The role of problems content in the selection task an THOG problem. IN Evans (1983).

Griggs, R.A. and Cox, J.R. 1982. The elusive thematic-materials effect in Wason's selection task. British Journal of Psychology, 73, 407-20.

Griggs, R.A. and Cox, J.R. 1983. The effects of problem content and negation on Wason's selection task. Quarterly Journal of Experimental Psychology, 35A, 519-33.

Griggs, R.A. and Newstead, S.E. 1982. The role of problem structure in a deductive reasoning task. Journal of Experimental Psychology, 8, 297-307.

Griggs, R.A. and Newstead, S.E. 1983. The source of intuitive errors in Wason's THOG problem. British Journal of Psychology, 74, 451-9.

Henle, M. 1978. Foreword to Revlin, R and Mayer, R.E. (eds). Human Reasoning. Washington, DC: Winston.

Inhelder, B. and Piaget, J. 1958. The growth of logical thinking from childhood to adolescence. London: Routledge and Kegan Paul.

Johnson-Laird, P.N. 1969a. Linguistic complexity and insight into a deductive problem. IN Flores d'Arcais, G.B. and Levelt, W.J.M. (eds). Advances in Psycholinguistics. 1970. Amsterdam-London: North Holland.

Johnson-Laird, P.N. 1969b. On understanding logically complex sentences. Quarterly Journal of Experimental Psychology, 21, 1-13.

Johnson-Laird, P.N. 1983. Mental Models: towards a cognitive science of language, inference and consciousness. Cambridge: Cambridge University Press.

Johnson-Laird, P.N., Legrenzi, P. and Legrenzi, M.S. 1972. Reasoning and a sense of reality. British Journal of Psychology, 63, 395-400.

Johnson-Laird, P.N. and Tagart, J. 1969. How implication is understood, American Journal of Psychology, 2, 367-73.

Johnson-Laird, P.N. and Wason, P.C. 1970 A theoretical analysis of insight into a reasoning task. Cognitive Psychology, 1, 134-48.

Johnson-Laird, P.N. and Wason, P.C. (eds). 1977. Thinking: readings in cognitive science. Cambridge University Press.

Johnson-Laird, P.N. and Wason, P.C. 1977a. A theoretical insight into a reasoning task: and postscript. IN Johnson-Laird and Wason (1977).

Krauth, J. 1982. Formulation and experimental verification of models in propositional reasoning. Quarterly Journal of Experimental Psychology, 34A, 1-30.

Legrenzi, P. 1970. Relations between language and reasoning about deductive rules. IN Flores D'Arcais, G.B. and Levelt, W.J.M (eds). Advances in Psycholinguistics, Amsterdam-London: North Holland.

Lemmon, E.J. 1965. Beginning logic. London: Nelson.

Mandler, J.M. 1980. Structural invariants in development. IN Liben, L. (ed). Piaget and the Foundations of Knowledge. Hillsdale, N,J.: Erlbaum.

Manktelow, K.I and Evans, J.St.B.T. 1979. Facilitation of reasoning by realism: effect or non-effect? British Journal of Psychology, 227-31.

Minsky, M. Frame-system theory. 1977. IN Johnson-Laird and Wason, 1977.

Newstead, S.E., Griggs, R.A. and Warner, S.A. 1982. The effects of realism on Wason's THOG problem. Psychological Research, 44, 85-96.

Pollard, P. 1981. The effect of thematic content on the 'Wason selection task'. Current Psychological Research, 1, 21-9.

Pollard, P. 1982. Human reasoning: Some possible effects of availability. Cognition, 10, 65-96.

Popper, K.R. 1959. The logic of scientific discovery. London: Hutchinson.

Reich, S.S. and Ruth,P. 1982. Wason's selection task: verification, falsification and matching. British Journal of Psychology, 73, 395-405.

Rips, L.J. 1986. Mental muddles. IN Brand, M. and Harnish, R.M. (eds). Problems in the Representation of Knowledge and Belief. Tucson, Arizona: University of Arizona Press.

Rips, L.J. and Marcus, S.L. 1977. Suppositions and the analysis of conditional sentences. IN Just, M.A. and Carpenter, P.A. (eds). Cognitive Processes in Comprehension. New York: Wiley.

Roberge, J.J. 1974. Effects of negation on adults' comprehension of fallacious conditional and disjunctive arguments. Journal of General Psychology, 91, 287-93.

Roberge, J.J. Effects of negation on adults' disjunctive reasoning abilities. 1976a. Journal of General Psychology, 94, 23-8.

Roberge, J.J. 1976b. Reasoning with exclusive disjunctive arguments. Quarterly Journal of Experimental Psychology, 28, 419-27.

Roberge, J.J. 1978. Linguistic and psychometric factors in propositional reasoning. Quarterly Journal of Experimental Psychology, 30, 705-16.

Rosenthal, R. 1978. Combining results of independent studies. Psychological Bulletin, 85, 185-193.

Smyth, M.M. and Clark, S.E. 1986. My half-sister is a THOG: Strategic processes in reasoning. British Journal of Psychology, 77, 275-87.

Turner, D.H. 1982. The effects of familiar relations on Wason's THOG problem. Unpublished final year project. University of Keele.

Van Duyne, P.C. 1974. Realism and linguistic complexity in reasoning. British Journal of Psychology, 65.1, 59-67.

Wason, P.C. 1966. Reasoning. IN Foss, B. (ed.) New Horizons in Psychology. Harmondsworth, Middx.: Penguin.

Wason, P.C. 1977. Self-contradictions. IN Johnson-Laird and Wason (1977).

Wason, P.C. 1983. Realism and rationality in the selection task. IN Evans (1983).

Wason, P.C. and Brooks, P.G. 1979. THOG: the anatomy of a problem. Psychological Research, 41, 77-90.

Wason, P.C. and Johnson-Laird, P.N. 1969. Proving a disjunctive rule. Quarterly Journal of Experimental Psychology, 21, 14-20.

Wason, P.C. and Reich, S.S. 1979. A verbal illusion. Quarterly Journal of Experimental Psychology, 31(4), 591-7.

Wason, P.C. and Shapiro, D. 1971. Natural and contrived experience in a reasoning problem. Quarterly Journal of Experimental Psychology, 23, 63-71.

Wickelgren, W.A. 1973. How to solve problems: Elements of a theory of problems and problem solving. San Francisco: Freeman.

Yachanin, S.A. and Tweney, R.D. 1982. The effect of thematic content on cognitive strategies in the four-card selection task. Bulletin of the Psychonomic Society, 19, 87-90.

Appendix A

Written instructions given to subjects participating in Experiment 1

Rick is spending his summer holidays fruit picking. The farmer he works for is very keen that only fruit in perfect condition should be picked, to avoid wastage. He tells Rick to judge the condition by the colour.

On each of the following four pages is a diagram similar to that shown below showing four cards. Each has the colour of a fruit on one side and its condition on the other side. Two of the cards show the fruit's colour uppermost, and have its condition on the other side. The other two show the condition uppermost, and have the colour on the other side.

Each diagram is accompanied by a sentence summarizing what the farmer tells Rick about the fruit to which the cards on that page refer. Your task is to decide which of the cards you would need to turn over in order to find out whether the farmer is right in what he says about the fruit.

Please put a tick (✓) below the box(s) representing the cards you would need to turn over in order to decide whether the farmer is correct or not, and a cross (x) below those you would not need to turn over. Please work through the booklet from front to back, and do not change any answer after you have looked at a later page. You may refer back to this page if necessary. Begin as soon as you are ready.

ABSTRACT BINARY PROBLEMS

Illustrated below are four cards, two showing a letter 'B' or 'C' and two showing a number '3' or '4'. These cards are taken from a pack in which every card has a letter 'B' or 'C' on one side and a number '3' or '4' on the other. Hence each card showing a letter uppermost has a number '3' or '4' on the other side, and each card showing a number uppermost has a letter 'B' or 'C' on the other side.

On each of the following four pages is a similar diagram together with a statement about what symbols appear on the four cards. Your task is to decide which of the cards you would need to turn over in order to find out whether the statement is true or false.

Please put a tick (✓) below the box(s) representing the cards you would need to turn over in order to decide whether the statement on that page is true or false, and a cross (x) below those you would not need to turn over.

Please work through the booklet from front to back, and do not change any answer after you have looked at a later page. You may refer back to this page if necessary. Begin as soon as you are ready, and when you have finished please answer the question below.

ABSTRACT MULTIPLE PROBLEMS

Illustrated below are four cards, two showing a letter and two showing a number. These cards are taken from a pack in which every card has a letter on one side and a number on the other. Hence each card showing a letter uppermost has a number on the other side, and each card showing a number uppermost has a letter on the other side.

On each of the following four pages there is a diagram showing four such cards together with a statement about what symbols appear on them. Your task is to decide which of the four cards you would need to turn over in order to find out whether the statement is true or false.

Please put a tick (✓) below the box(s) representing the card(s) you would need to turn over in order to decide whether the statement on that page is true or false, and a cross (x) below those you would not need to turn over.

Please work through the booklet from front to back, and do not change any answer after you have looked at a later page. You may refer back to this page if necessary. Begin as soon as you are ready.

Appendix B

Instructions presented to subjects on printed sheets and displayed on the computer monitor in Experiment 5.

In what follows the points in the computer display when subjects would need to press the 'Return' key are indicated by ">" on a line by itself.

During the course of this experiment you will often be asked to press 'Return' to continue. The 'Return' key is on the right of the keyboard. Please press 'Return' now.

>

Thank you. Sometimes you will be asked to type in an answer. When you have finished typing your answer it will always be necessary to press 'Return' in order to continue. Please press 'Return' again.

>

If you make a mistake when typing an answer, you may return to the point at which the mistake was made by pressing the key with an arrow pointing to the left. It is just below and to the left of the 'Return' key.

If you change your mind about the whole answer press 'Return' and you will be given the chance to start again.

Press 'Return' to continue.

>

Please type your answer to the following question, remembering to press 'Return' afterwards.

What is your first name?

>

Thank you <name as entered>.

What is your last name?

>

That is the end of the preliminary instructions. If any of the details which follow are not at first clear you may refer to them again by looking at the printed sheet on which they are repeated. If anything remains unclear, please ask the experimenter for clarification.

Please imagine you are playing a card game in which you are allowed to write down an instruction which will tell your partner whether to accept each of four pairs of cards. He will draw the first card of each pair from a pack of letter cards, and the second from a pack of number cards.

The first card will always be 'B' or 'C', and the second card will always be '3' or '4'.

Press 'Return' to continue.

>

Below is a table showing the four possible combinations of symbols on the pairs of cards, and whether the pair should be accepted.

B 3 Accept

B 4 Do not accept

C 3 Do not accept

C 4 Do not accept

More rules are to follow, and you will be shown this table again.

Press 'Return' to continue.

>

When giving the instruction you must not type 'C' or '4'. You will also lose points if you mention 'B' or '3' more than you need, although you must mention them as many times as necessary in order to make the instruction clear to your partner.

Press 'Return' to continue.

>

In addition to remembering not to mention 'C' or '4', and to mention 'B' and '3' as few times as possible, you should also try to make sure that your instruction is precise, so that anyone looking at the four pairs of cards, as in the example, would be able to say of every pair whether it should be accepted or not.

Press 'Return' to continue.

>

For example "Accept B and 3" is not sufficient since it is

uninformative about the other pairs. "Accept B and 3 only" is better, but it is not clear whether it refers to the pair 'B 3' or to 'B' and '3' individually. Therefore, a better instruction would be "Accept only the pair 'B 3'". Another good answer is "The letter must be B, and the number must be 3".

Press 'Return' to continue.

>

Alternatively "Do not accept any pair except 'B 3'" is also clear. In these cases it would be possible to decide about the acceptability of all four pairs from these instructions. 'B' and '3' are mentioned only once, so these instructions mention them as little as possible.

Press 'Return' to continue.

>

In giving your instructions you may use similar wording to that used in these examples, or you may depart from it completely. The main thing is that the instruction must be completely clear to you.

Press 'Return' to continue.

>

Here is the table again. Please type in your instruction in your own words.

B 3 Accept

B 4 Do not accept

C 3 Do not accept

C 4 Do not accept

My instruction is:

>

If you are sure that you instruction is clear enough for someone to draw up the table given only the four possible pairs of cards, press 'Y', otherwise press 'N' to try again.

>

< The four conditional tables mentioned in the main text were then presented in randomized order in a similar manner to the above, and the responses stored on a disc. The second part of the experiment then commenced.>

Thank you < name as entered >. Please wait for a moment. Now it is your turn to be the other partner in the game. This time the letter cards are 'V' and 'W' and the number cards are '6' and '7'. Please ask the experimenter for an instruction sheet relating to this second section.

Please press 'Return' when you are ready to continue.

>

As the other partner in the game you have drawn four pairs of cards, but one card of each pair is face down. Your task is to say which of the face-down cards must be turned over in order for you to decide whether to accept the pair of which it is a member. Face-down cards will be indicated by '*'.

Press 'Return' to continue.

>

For each paired face-down card which you would need to turn over in order to decide whether the pair is acceptable, type the symbol on the card with which it is paired. If you think that none of the face-down cards needs to be turned over, type 'none'.

Press 'Return' for an example.

>

For example, if you were shown this-

The instruction is:
The letter must be a 'V'.

V *

W *

* 6

* 7

- you would be able to say that 'V *' is an acceptable pair, and 'W *' is not without needing to turn over the number cards. However, you would need to turn over the letter cards in the pairs '* 6' and '* 7' in order to decide whether they were acceptable.

You would therefore type '6 7'.
Press 'Return' to continue.

>

Remember that the aim is to turn over each card which it is necessary to see in order to decide whether the pair of which it is a member is acceptable, but not to turn over any card unnecessarily. If you should want to restart your answer, type any letter other than 'V' or 'W'.
Press 'Return' to continue.

>

Thank you < name as entered >. Please wait for a moment.
Please type which cards must have their paired face-down card turned over in order to decide whether the pair is acceptable according to this instruction.

The instruction is:

If the letter is 'V', then the number is '6'.

V *

K *

* 6

* 7

The cards paired with the following must be turned over:

>

The instruction in the above example could have been any one of the four standard wording or four subject's wording conditionals. The remaining seven problems were then presented in the same way in randomized order and the responses stored on disc.

Appendix C

Examples of three subjects' own formulations in response to the "If the letter is 'B', then the number is '3'" table in Experiment 5. The table is shown below and is the first table on page 82.

B 3 Accept

B 4 Do not accept

C 3 Accept

C 4 Accept

Example 1: "Accept everything, except, accept B only when it occurs with a 3". (Classified as a 'p only if q' formulation).

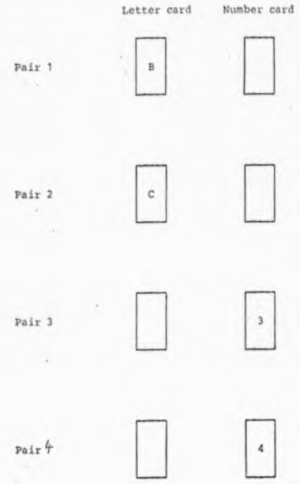
Example 2: "Take any pairs except when B is not with 3.
(Classified as a 'Not both p and not-q' formulation).

Example 3: "If the letter is not 'B', or the number is '3' then accept".
(Classified as a 'Not-p or q' formulation).

Appendix D

Written instructions given to subjects participating in Experiment 6

On each of the following pages there is a diagram like the one below. In every case the diagram represents four pairs of cards which are as follows:- The card on the left of each pair always has a letter on it which is either 'B' or 'C'. In pairs 3 and 4 the letter card is face-down, so you cannot see which of these letters is on it. The card on the right of each pair always has a number on it which is either '3' or '4'. In pairs 1 and 2 the number card is face-down, so you cannot see which of these numbers is on it.



The problem is always to decide which of the face-down cards you would need to turn over in order to find out about the truth of a rule concerning the combination of letter and number on each pair of cards.

For all 8 pages you are asked to put a tick '√' in the box(s) representing the face-down card(s) you would need to turn over in order to decide whether the rule given on that page is true.