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ABSTRACT

In an experiment using a conditional logic task, subjects were given a set of cards defining a particular conditional relationship. The subjects were required to determine the rule and predict the outcomes of the rule. Rule structure was varied by providing subjects with either a suggested rule, a partial rule, or no rule for each set of cards. Other factors that were manipulated included problem type (use of negations in syllogisms) and problem dimensionality (level of task difficulty based on number of choice items). It was found that when task difficulty was low, subjects with the most rule structure used a matching strategy and showed higher error rates than those with less rule structure. When task difficulty was high, all subjects showed the matching strategy. Qualitative differences were found in the errors made by the two groups, suggesting the need for further research on both qualitative and quantitative differences in conditional problem solving. Appended tables present statistical data from the experiment. (Author/MSE)

THE ROLE OF RULE CONTENT INTERFERENCE AND TASK DIFFICULTY IN CONDITIONAL LOGIC PROBLEM SOLVING

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ABSTRACT

In a conditional logic task, subjects were given a set of cards which defined a particular conditional relationship. The subjects were required to determine the rule and predict the outcomes of the rule. Rule structure was varied by providing subjects with either a suggested rule, a partial rule, or no rule for each set of cards. Other factors which were manipulated included problem type (use of negations in syllogisms) and problem dimensionality (level of task difficulty based on number of choice items). It was found that when task difficulty was low, subjects with the most rule structure used a matching strategy and showed higher error rates than those with less rule structure. When task difficulty was high, all subjects showed the matching strategy.

Previous research (Manktelow & Evans, 1979; Pollard & Evans, 1980) has suggested that non-logical biases or tendencies account for a significant portion of logical reasoning performance. These studies have indicated that subjects tend to use a matching strategy when solving problems involving logical syllogisms. It has been suggested that one source of this matching is rule content interference. Content interference refers to errors which are related to focussing attention primarily on the content elements of a logical syllogism at the expense of attending to the logical form or requirements of the problem. One view of content interference suggests that there is a set of possible solutions that can be generated by subjects which include elements contained in the logical syllogism itself (e.g., If p then q; p and q are possible solution). The presence of these elements predispose the subjects' attention towards selecting these content-based rather than logic-based solutions A second factor, task difficulty, promotes matching by increasing the processing load for solving problems in working memory. Specifically, more representational space is required to encode tasks with higher degrees of difficulty. These factors do not necessarily act as distractors, but rather simply place more demands on processing. Therefore, the greater the demands placed on subjects make them more susceptible to errors in performance.

Traditional conditional logic tasks, like the Wason four-card problem (Wason, 1968), have confounded conditional reasoning and content interference and also have ignored the question of level of task difficulty. The Wason task involves the use of a conditional rule of the form "If p then q" and the selection of four cards representing p, $\bar{p}$ (not p), q, and $\bar{q}$ (not q) to test the rule. The task is typically presented in a symbolic form where the subjects are shown four cards (A, D, 4, and 7) and a rule which states "If there is a vowel on one side of the card, then there is an even number on the other side." The subjects are told that each of the cards has a letter on one side and a number on the other side. The subjects are asked to select the cards (and only those cards) which are necessary to turn over to determine whether the rule is correct or incorrect. The correct solution is p and $\bar{q}$ (A and 7) since only this combination can falsify the rule.

In its abstract form, this task has proved to be quite difficult even to highly intelligent subjects. Wason and Shapiro (1971) reported that only about 4% of the undergraduate college subjects studied succeeded at getting the correct solution (see Table 1). The combined results from four studies by Wason showed that fewer than 10% were able to produce the correct solution (see Wason & Johnson-Laird, 1970 for review). An examination of the responses indicated that two general errors occurred which account for about 80% of all incorrect responses. The first error involved the selection of the p-card, but failure to select the $\bar{q}$-card. This error is commonly known in logic as a failure to apply <u>modus</u>

tollens (i.e., If p, then q; given not q, therefore not p). The second error, known as "affirming the consequence", is found in the selection of the p-card and the q-card. Table 1 presents a review of the relative frequencies of these and other observed responses.

Several explanations have been offered in the literature to account for these errors {see Evans (1978) and Johnson Laird & Wason (1977) for recent reviews}. Johnson-Laird and Wason (1970) argued that the subjects attempted to verify rather than to falsify the rule. This particular behavior involved the response selection of the p-card only or the p-card and q-card. Evans and Lynch (1973) rejected the Johnson-Laird and Wason (1970) verification model and suggested that subjects were merely matching the letters in the conditional statement with the letters on the card (i.e., it appears that the letters were acting as content interference). In the "If p then q" rule, both the verification and matching hypotheses predict the selection of the p-card and the q-card. However, Evans and Lynch noted that if the conditional statement were changed to the "If p then not q", the verification hypothesis would predict the choice of the p-card and the $\bar{q}$-card while the matching bias hypothesis predicted the choice of the p-card and the q-card. Similar biases could be obtained for the conditional statements of "If not p then q" and "If not p then not q." Evans and Lynch found support for the matching bias hypothesis over the verification hypothesis in that subjects are often focused on just the p- and q-cards regardless of whether the "not" was present or absent.

An important short-coming of the matching bias hypothesis and other models which have been proposed is that they are based solely on data from the Wason four-card problem (or analogous problems) and, thus, subject to certain idiosyncrasies within the task. Specifically, the Wason problem is a rule testing procedure in which a rule is presented from which subjects are required to evaluate the rule and draw conclusions about it. The performance is said to reflect the ability to use conditional reasoning. However, this matching bias is dependent upon the presentation of the rule itself rather than any particular logical inference derived from the rule. In effect, the rule presentation may be acting to interfere with performance and, therefore, may obscure competence in conditional reasoning. Roth (1979) found that when the p-card was removed as a possible solution (thus eliminating the possibility of matching the p in the syllogism with the choice of the p-card), he was able to eliminate some of the matching bias. The removal of this source of bias resulted in an overall improvement in solving the conditional reasoning task. These data strongly suggest that the antecedents and consequents of the logical rule may be a source of interference in task performance. Therefore, it is suggested that in order to study the level of competency in conditional reasoning, this potential source of interference should be minimized.

The present study was designed to control the level of content interference by changing the traditional Wason four-card problem from a rule-testing to a rule-production task. In this task, subjects were provided with all relevant cards that were designed to define a specific conditional rule and their task was to: (a) determine a conditional rule for the set of cards; (b) make predictions about the cards based on the rules; and (c) test the rule according to the traditional Wason problem methods.

As previously indicated, content interference appears to act as a distractor in conditional reasoning problem solving behavior. This involves the subject's tendency to show a preference in selecting elements which are contained in the logical argument as solution items. In the present study, content interference was manipulated by incorporating three different levels of rule structure in which (1) content interference was present in a conditional rule, (2) content interference from the antecedents and consequents was removed in a conditional rule, and (3) all sources of content interference were removed in a conditional rule. In the rule condition, a rule was provided which should produce similar content interference to that reported in the traditional Wason four-card problem (e.g., "If A then 1", "If B then not 2", etc.). In the partial rule condition, the antecedents and consequents were removed while the remainder of the rule was provided (e.g., "If

____ then ____", "If ____ then not ____", etc.). This condition eliminates antecedent and consequent sources of content interference which had been hypothesized to inhibit performance but still contains the basic structure of the rule. In the no rule condition, the subjects were given no specific rule structure but must induce a rule from the cards. This condition eliminates all sources of content interference. It was expected that by providing subjects with different levels of rule structure, more potential content interference was introduced into the task and thereby promoted a matching bias strategy. Comparisons between the different rule conditions would provide information about the role of content interference in conditional reasoning. To further facilitate the examination of the effects of content interference, the traditional Wason four-card problem was presented prior to and after the administration of the modified rule-production task. It was hypothesized that performance on the rule-production task would generalize (since it involves conditional reasoning and immediately follows the rule-production task) to the Wason four-card problem and thus there would be differences in performance in the Wason task given before and after the rule-production task depending on the particular rule presentation condition.

Several hypotheses were entertained in the present study with regard to the ru production task. It was expected that as the degree of content interference decreased, conditional reasoning performance would be increased. Specifically, in the rule-production task, significantly fewer errors would be made by subjects in the no rule condition, as compared to the partial rule condition, while the rule condition subjects were expected to show the greatest reasoning error rate. Furthermore, similar error relationships across the three rule conditions were expected to be found when the traditional Wason four-card task given prior to the rule-production task was compared to performance on the Wason four-card task given after the rule-production task. It was expected that the removal of content interference in the rule-production task would generalize to the second Wason four-card task and thereby produce performance improvement in the no rule condition, some improvement in the partial rule condition, and little or no improvement in the rule condition. It was further hypothesized that differential performance across the rule conditions would only be observed in subjects who were at the formal operational level rather than the concrete operational level since conditional reasoning itself was considered to be a formal operational ability. Thus an interaction between rule presentation condition and cognitive level is expected.

In the rule-production task, two levels of task difficulty were examined. The conditional problems contained either two antecedents and two consequents or three antecedents and three consequents. Consistent with the limited representational space interpretation, it was expected that the 3-dimensional problems would be more difficult than the 2-dimensional problems. It was also expected that task difficulty would interact with rule presentation condition since the 3-dimensional condition represents an increase in interfering elements. As content interference increases, the potentials for task difficulty become more important bacause of the overall increase in processing requirements. Therefore more errors are likely to occur when content interference factors are present with higher problem dimensionality since the likelihood of overcoming content interference is decreased by increased task difficulty.

METHODS

Subjects

A total of 118 college undergraduate students enrolled in introductory psychology at Northern Illinois University served as subjects in this study. This sample consisted of 57 males and 61 females with a group mean age of 19.6 years. Initially, all subjects were administered a paper and pencil formal operations test (see Rycek, 1983) in a large group setting. Based on this screening test, 30 subjects who showed predominantly concrete level thinking and 30 subjects who showed predominantly formal level thinking were randomly selected to serve as the experimental subjects. Subjects for each of these two groups were randomly assigned to one of three rule conditions with half being from each sex. In subsequent experimental procedures, all subjects were tested individually.

Conditional Reasoning Task

Eight problems made up the conditional reasoning task for each subject. Each problem consisted of a set of 12 Wason-type cards that defined a particular logical implication rule of either: If p then q; If p then not q; If not p then q; or If not p then not q. Half of the problems were the standard Wason four-card problem form (2 antecedents and 2 consequents) and the other hal odified six-card problem form (3 antecedents and 3 consenque ith the individual cards representing all logical deductions of the rule. The four-card problem was used because this version closely replicates the traditional Wa n-card procedure. However, in the case of the no rule condition, the logic was such that the four-card situation yielded four possible correct rules (e.g., "If A then 1", "If A then not 2", "If not B then 1", and "If not B then not 2"). In the six-card version, this problem does not arise since only one unique rule solution is possible. Therefore, the four-card was used to replicate Wason-cards for all conditions while the six-card version overcame the unique problem in the no rule condition. The antecedents were either "A" and "B" for the four-card problem form or "A", "B", and "C" for the six-card problem. The consequents were either "1" and "2" for the four-card problem form or "1", "2", and "3" for the six-card problem. Each card consisted of an antecedent on one side and a consequent on the reverse side. The rules for the task were of the form: "If there is an A on one side of the card then there is a 1 on the other side." Each was also provided with either a rule (e.g., "If A then 1", "If A then not 1", etc.), a partial rule (e.g., "If ____ then ____", "If ____ then not ____", etc.), or no rule. Subjects were given a packet of 12 cards from which they were instructed to determine the rule. For example, if the rule was "If A then no 1", the subject was given a set of 12 cards consisting of A/2 (side 1 / side 2), A/2, A/3, A/3, B/1, B/2, B/3, B/3, C/1, C/2, C/2, C/3. All problems were administered in a random order to each subject.

Procedure

All subjects were administered a traditional Wason four-card problem. The subject was shown four cards (e.g., a square, a triangle, an "X", and an "O") and given the rule "If there is a square on one side of the card, then there is an X on the other side." The subject was told that on one side of the card there was either a square or a triangle and on the other side there was either an "X" or an "O". He was asked to indicate which card or cards he needed to turn over in order to check if the rule was correct and to explain his answer. After this was completed, he was asked to predict what could be on the other side of each card according to the rule. The subject was also asked how he would prove the rule true and how he could prove the rule false.

After the subject completed the Wason problem, the conditional rule-production task was introduced to the subject as follows. The subject was initially presented with a set of four sample cards (Z/5, Z/5, K/5 and K/7) and was shown that there was a letter on one side and a number on the other side of each card. The subject was told that he would receive cards like these only there would be 12 cards in each set rather than four. He was told that each set of cards denoted a specific rule of the four forms: "If there is a certain letter on one side, then there is a certain number on the other side; If there is a certain letter on one side, then there is not a certain number on the other side; If there is not a certain letter on one side, then there is a certain number on the other side; and If there is not a certain letter on one side, then there is not a certain number on the other side." All the rules were read to the subject and were available on a written card throughout the session. The subject was told that a rule for the sample cards could be: "If there is a Z on one side, then there is a 5 on the other side." An examination of each card was made to show that the rule was true, but no explanation was given. The subject was told that he would be dealing with letters and numbers that were either "A, B, 1, and 2" or "A, B, C, 1, 2, and 3" and that he would be told which set it was before each problem. The four or the six letters and numbers were printed on a large card and were used as a reference for the subjects throughout the tasks. The subject was also told that he could manipulate the cards in any way he wished. The subject was then told about his specific condition.

Rule. In the rule condition, the subject was presented with a rule (which was actually the correct rule) for each set of cards and told that it might be a rule for the set of cards. The subject was instructed to first check to see if the rule was correct for the set of cards. If the subject determined it was correct, he was asked to explain why it was correct. If the subject determined it was incorrect, he was also asked to explain why it was incorrect and asked if he could find a rule that was correct for the set of cards. In either case, the subject was asked to base his predictions on the rule that was given first and then afterwards to make predictions based on his alternate rule.

Partial rule. In this condition, the subject was presented with the appropriate rule form and instructed to find a rule using that particular rule form. If the subject was unable to find a rule using the given rule form, he had the option to use any rule form. Once the rule was determined, the subject was asked to specifiy the rule and explain why it was correct.

No rule. In the no rule condition, the subject was not given any guidance as to what rule or rule form should be used first. As in the other conditions, the subject did have access to a card that contained all the rule form possibilities. When the subject had determined a rule, he was asked to specify the rule and explain why it was correct.

After the rule had been explained by the subject, the procedure for all the conditions was the same. The subject was asked to predict, according to the rule, what could be on the other side of each of the antecedent and consequent cards. The experimenter went through each antecedent and consequent individually with the subject. After the predictions were made, the subject was asked to test the rule by indicating which card or cards needed to be checked in order to see if the rule was correct. The subject was told to indicate only those cards which were necessary to check according to the rule and then he was asked to explain his choices. Next the subject was asked to indicate how the rule could be proved false and how the rule could be proved true and to explain his response. Finally, the subject was asked to evaluate the rule when the experimenter asked the subject if he thought the rule was correct for all the cards. If the subject indicated the rule was incorrect or not correct for all the cards, he was asked why and directed to see if he could find a rule that was correct using the available rule forms. If another rule was given, the procedures above were repeated in terms of predictions, testing, proving, and evaluation. Only one additional rule was examined for each set of cards. If the subject said the rule was correct, then the experimenter presented the next problem.

Once all eight problems were completed, the experimenter again presented a version of the traditional Wason four-card problem. The same procedures as indicated above were followed.

Scoring

In the prediction portion of the task, errors of omission (items that should have been included but were not) and commission (items that were included but did not belong) were obtained for each problem. Each instance of either an omission or commission was scored as one error. For the rule testing portion of the task, errors of omission and commission were again tabulated. In the rule proving portion of the task, correct or incorrect responses were recorded. The traditional Wason problems given at the beginning and the end of the rule-production task were also scored in similar manners as described above.

RESULTS

It was proposed that one factor involved in solving conditional logic problems was the degree of content interference present in a problem. In the traditional Wason problem, it was indicated that the rule might be a source of content interference. The present study was designed to examine this potential source of interference by varying the level of rule structure in a rule-production task. It was hypothesized that as the level of rule structure was decreased, the level of performance on conditional reasoning problems should increase.

Pre- and post-test Wason problems. One way in which this hypothesis was tested was to examine the pre- and post-test responses on the traditional Wason problems. While the traditional Wason problems contain the hypothesized interfering elements, it was felt that a differential carry-over effect from the various experimental conditions would be observed. Specifically, it was hypothesized that the greatest improvement in performance would be found in the no rule condition as compared to the partial rule condition, while the rule condition subjects were expected to show the least improvement in performance.

To test this hypothesis, a 2(Cognitive Level) X 3(Rule Presentation) X 2(Time of Test) analysis of variance with repeated measures on the last factor was performed. The levels of the cognitive factor were concrete and formal; the rule presentation factors were rule, partial rule, and no rule; and the time of test factors were pre- and post-test. The dependent measures for this analysis were the total number of errors recorded in the prediction, test, and proof phases of the problems. The ANOVA revealed significant main effects for cognitive level {$F(1, 54) = 38.01$, $p < .01$} and for time of test {$F(1, 54) = 8.20$, $p < .01$}. However, the predicted interaction between rule presentation and the time of test was not found. The results indicate that formal operational subjects generally made fewer errors ($M = 4.28$) on the Wason tasks than the concrete operational subjects ($M = 8.32$). This result was not unexpected since formal subjects generally perform better on conditional reasoning tasks. The other main effect indicates a within subjects change in which subjects made fewer errors in the post-test ($\underline{M}$ = 5.70) as compared to the pre-test ($\underline{M}$ = 6.90). This result indicates that while the different rule presentation conditions did not have any differential effects on post-test Wason problem performance, there may have been overall facilitation of performance based on the experiences in the rule production task. This notion is further strengthened by the fact that simply having experience with Wason problems does not seem to improve performance (Pollard & Evans, 1980) when given in this way. Based on these results, the hypothesized relationship suggesting differential generalizability of the rule presentation condition cannot be supported; rather the results suggest overall facilitation of performance.

Rule production task. Of more specific interest to the present study is whether there are interfering elements in logical problem solving. For this reason, the focus of this portion of the study is on the performance observed under the various rule presentation conditions when the interfering elements are directly manipulated. Several factors were hypothesized to influence performance on the conditional reasoning tasks. As previously indicated, it was hypothesized that in the rule production task the amount of rule structure given in a conditional logic problem will influence performance so that the more structure provided, the greater the chance for interference. Therefore, in the present study, it was hypothesized that the rule condition would provide the greatest potential for interference, followed by the partial rule and the no rule conditions respectively. It was also hypothesized that only subjects at the formal operational level would potentially be able to solve conditional logic tasks. Therefore, they would be the only subjects to benefit from reduced content interference; concrete operational subjects should not be influenced by the removal of content interference. A third factor of concern was task difficulty as represented by the use of negations in logical syllogisms. It was hypothesized that as task difficulty increases, the potential for interference becomes magnified. The logical syllogisms presented had either two antecedents and two consequents or three antecedents and three consequents. This was necessitated by the nature of logical solution sets in the no rule condition. It was hypothesized that the 3-dimension case would be more difficult than the 2-dimension case.

To test these hypotheses, multivariate techniques were employed. The main analyses consisted of several 2(Cognitive Level) X 3(Rule Presentation) X 2(Problem Dimension) X 4(Problem Type) multivariate analyses of variance (Finn, 1974) using the error rates on the prediction, test, and proof phases of the task as dependent measures. The first two factors were between subjects measures (Cognitive Level: concrete and formal; Rule Presentation:

rule, partial rule, and no rule) while the other factors {Problem Dimension: 2 and 3; Problem Type: If not p then q (AA), if p then not q (AN), if not p then q (NA), and if not p then not q (NN)} were within subjects measures. A four-way interaction among these factors was predicted. This interaction was expected to show that only formal level subjects are differentially influenced by the other conditions while concrete subjects show high and equal error rates across all conditions. For the formal subjects, the 2-dimensional problems were expected to show that errors in the rule and partial rule conditions increased across problem type with the rule condition showing a higher, but parallel, error level. The 2-dimensional no rule condition would show the lowest error rate with no difference across problem type. The 3-dimensional problems would show increasing error rates for all rule presentation conditions across problem type with the rule condition showing the highest level, followed by the partial rule and the lowest level for the no rule condition. Since each phase of the rule production task represents a different aspect of conditional logic problem solving, separate analyses were conducted for each phase.

Prediction phase. The first of these analyses examined errors made during the prediction portion of the rule production task. During the prediction phase, subjects were asked to predict what would appear on the bottom side of a card given a particular symbol on the top side. This task required the subjects to apply the rule to a specific case and predict the possible outcomes. Table 2 provides a summary of the mean total errors for the prediction phase over all conditions. The results of the MANOVA on these data are given in Table 3. According to these results, the four-way interaction was not significant; however, several lower level interactions were. The results indicate a significant Rule Presentation X Problem Dimension X Problem Type interaction. For this triple interaction (see Figure 1), the 2-dimensional condition for the partial rule and no rule conditions show low and equal levels across problem type. The 2-dimensional rule condition, indicates low level error rates for the AA and AN problem types but higher error levels for the NA and NN problem types. In the 3-dimensional case, overall higher error rates are found in the three rule presentation conditions for the AA, NA, and NN problem types. The AN problem type shows lower error levels under all conditions. The critical points in this interaction are the NA and NN points for the rule and partial rule conditions across problem dimensionality. These results support the content interference hypothesis which predicted higher error rates in the rule condition. Additional lower level interactions were found in these data (see Table 3). A Cognitive Level X Problem Dimension interaction was also significant (see Figure 2) which indicates that while both concrete and formal operational subjects found the 3-dimensional problems more difficult than the 2-dimensional problems, the concrete subjects found the 3-dimensional more difficult than the formal subjects. These data support both the notion that concrete subjects find conditional reasoning more difficult than the formal subjects and that 3-dimensional problems were more difficult than the 2-dimensional problems. The interaction as pictured in Figure 2, however, is not particularly convincing evidence for differential effects of cognitive level. This result will be discussed in greater detail later.

The results for the total error data for the prediction phase were somewhat ambiguous but yielded some support for the hypotheses concerning conditional logic problems. As expected, formal subjects made fewer errors (M = 0.63) than concrete subjects (M = 1.39). It appears that the differences between formal and concrete subjects were consistent across most of the rule presentation conditions. Rule Presentation did interact with problem dimensionality, but no main effect was found. Problem Dimension showed the expected relationship with the other factors with the 3-dimensional having more errors (M = 1.52) than the 2-dimensional problems (M = 0.50).

It is possible that the dimensionality effects might be a product of the fact that there are a greater number of possible errors that can be made in the 3-dimensional case as compared to the 2-dimensional case in each problem. To examine this possibility, analyses using error proportions were conducted. The results of these analyses were consistent with those reported here, since it did not appear that the effects were due to different error potentials. All of the results were replicated and, in fact, the relationships proved to be stronger with the proportional data. In addition, the 2-dimensional and 3-dimensional data were analyzed separately as a further check for possible influences. Again, these analyses indicated that the other effects were sufficiently robust that they were not affected by the different error potentials.

Test phase. During the test phase, subjects were asked to indicate which card or cards were necessary to check in order to determine whether the rule was correct or incorrect. This was analogous to the procedures used in the standard Wason task. Table 4 provides a summary of the mean total errors for the test phase over all conditions. The results of the MANOVA on these data are given in Table 5. The Problem Dimension X Problem Type interaction (see Figure 3) was the only significant interaction in this analyses. This interaction indicates differential error rates among the problem types for the 3-dimensional problems with stable error rates for the 2-dimensional problems; the latter rate remains relatively low. No differences were found for the AN problems while the greatest differences were found for the NA problems. Consistent with the previous results for the prediction phase, main effects for Cognitive Level, Problem Dimension, and Problem Type were found.

Proof phase. During the proof phase, subjects were required to give a verbal response indicating how they would prove their rule to be true and how they would prove their rule to be false. Each of these questions was scored on a correct/incorrect scale. Based on this MANOVA, a single main effect for Cognitive Level was found which indicates that concrete operational subjects made more incorrect responses (M = 1.24) than formal operational subjects (M = 0.82) over all problems {$F(1,54) = 21.27$, $p < .01$}. No other factors were significant.

DISCUSSION

The results support the content interference hypothesis in that the rule presentation condition showed decreased performance (increased errors) under some conditions. However, as evidenced by the Rule Presentation X Problem Dimension X Problem Type interaction for the prediction phase data (see Figure 1), content interference interacts with task difficulty.

Previous research (Manktelow & Evans, 1979; Pollard & Evans, 1980) had suggested that negations serve as a task difficulty variable in that the inclusion of the work "not" in a syllogism increases the processing load. Therefore, it was hypothesized that the order of task difficulty in solving conditional logic problems with negations was (from least to most difficult): If p then q (AA), if p then $\bar{q}$ (AN), if $\bar{p}$ then q (NA), and if $\bar{p}$ then $\bar{q}$ (NN). However these results have not always been consistent across studies using negations. For example, Roberge (1976) found that the use of negations in disjunctive arguments produced an order of difficulty (least to most errors) of AA < NN < NA = AN. Although disjunctives are different from conditionals, the addition of negations should have produced task difficulty changes simi.ar to those expected in conditionals. One explanation of th e results offered by Roberge was that the NN case was trea: a "double negative" by the subjects and translated into an AA form.

In the present study, the order of difficulty for conditional logic problems with negations was (mean total errors from least to most): AN (M = 0.56, AA (M = 0.77, NN (M = 0.95), and NA (M = 1.77). These results do not support the hypothesis concerning the role of negation as a task difficulty variable, rather they are consistent with a constant interference interpretation. According to the content interference hypothesis, there should be a matching between elements found in the syllogism and the elements that are selected as solutions. If matching strategy were used, the pattern of difficulty based on the number of errors would be AN < AA = NN < NA . Table 6 presents an example of the predicted solutions and number of errors for the different rule types across dimensionality based on the content interference hypothesis. This table indicates that NA problems should show twice the errors of either the AA or NN problems and that the AN problems should show no errors. This relationship is true across dimensionality with 3-dimensional problems showing more errors than 2-dimensional problems. The present data are consistent with these relationships. Therefore, based on these results it appears that the use of negation does not increase task difficulty. Instead, these results suggest that the use of "not" does not add any additional memory or processing load. Furthermore, the use of "not" appears to be ignored by the subjects in that they select solutions which contain the content elements alone (i.e., like those predicted by content interference in Table 6).

It was hypothesized that content interference should be the greatest in the rule condition, to a lesser degree in the partial rule condition, and the least amount in the no rule condition. The Rule Presentation X Problem Dimension X Problem Type interaction (see Figure 1) indicated support for this hypothesis. In the 2-dimensional case, the partial rule condition showed a consistently low error rate across all problem types. However, in the rule condition, there were higher error rates for the NA and NN problem types and approximately equal error rates for the AN and AA problem types as compared to the partial rule condition. The rule condition data for the 2-dimensional problems are consistent with the predictions made in Table 6 based on content interference for the AN, NA, and NN problem types; the partial rule condition does not follow this pattern. These data support the content interference hypothesis in that the rule condition provided subjects with the complete rule while the partial rule condition did not. The error patterns were consistent with what would be expected from a matching strategy in the rule condition but not in the partial rule condition. The no rule condition is not a relevant contrast since, as previously mentioned, all rule types are correct for all problems in this condition. Therefore, there is no discrimination between problem type for the no rule 2-dimensional case.

In the 3-dimensional case (see Figure 1), the results were somewhat different. Generally, there were more errors made in the 3-dimensional problems ($\underline{M}$ = 1.52) as compared to the 2-dimensional problems ($\underline{M}$ = 0.50). This result indicated that, as hypothesized, the 3-dimensional case had a higher level of task difficulty. All of the rule presentation conditions (rule, partial rule, and no rule) for the 3-dimensional problems appeared to follow the pattern of error responses outlined in Table 6. These data would seem to indicate that the subjects were using a matching strategy in solving the 3-dimensional problems. Generally, no differentiation was found between rule presentation conditions across problem types.

Two exceptions were the rule condition for the AN problem which showed fewer errors than the other rule presentation conditions and the partial rule condition for the NN problem, which showed fewer errors than other rule presentation conditions.

These results tend to support the content interference hypothesis, however, they appear to be dependent on task difficulty. It was hypothesized that the rule condition would show the effects of content interference more than the partial rule or no rule conditions. In the rule-production task, the subjects in the rule condition were initially presented with the correct rule for the set of cards. It was hypothesized that subjects in this condition would focus their attention on the elements of the rule and thereby interfere with the processing of the logical form and/or requirements of the syllogism. Subjects in the partial rule and no rule conditions did not have this source of interference and therefore would be more likely to focus their attention on the logical form and requirements of the task. Therefore, the partial and no rule subjects had a better chance of correctly solving the problems. This appeared to have occurred in the 2-dimensional case since the rule condition subjects follow the patter of error responses consistent with the matching strategy found with content interference. This was not the case for the 3-dimensional case since all subjects seemed to follow the matching strategy. It is suggested that these subjects may have been relying on the matching strategy because the demands of the task were greater in the 3-dimensional case. Therefore, subjects in the rule condition simply checked the rule they were given and relied on that rule throughout the task. They did not necessarily attend to the logical form or requirements of the syllogism at any point. Partial and no rule subjects, on the other hand, initially must discover a rule and thus were forced to attend to the logical form and requirements. In the 2-dimensional case, it appeared that the partial and no rule subjects continued to attend to the logical form and requirements of the syllogism throughout the task and, therefore, performed better than the rule condition subjects. However, in the 3-dimensional case it appeared that the partial and no rule subjects initially attended to the logical form and requirements of the task. Once a rule was established, they relied heavily on that rule and shifted their attention to the rule elements and thus content interference intervened. This seemed to be due to the greater demands of the task in the 3-dimensional case.

Based on this interpretation, content interference interacts with task difficulty. When the processing demands increase, subjects are more likely to focus their attention on readily available elements when solving conditional logic problems. This interpretation is consistent with Ross and DeGroot's (1982) research on probability reasoning which showed that when probability problems were made more difficult by including multiple probability computations, subjects tended to make "stand pat" errors which involved selecting an answer contained in the question.

The results indicate that content interference does not always reduce performance. In the case of the AN problems (see Table 6), it is suggested that content interference has a facilitating effect since following the matching strategy should produce correct performance. The lower error levels for the AN problems in the rule condition support this prediction as a facilitating effect in the present study (see Figure 1). The rule condition, which affords the greatest opportunity for content interference, showed lower error rates for both the 2- and 3-dimensional problems as compared to the other problem types. These results provide strong evidence for the content interference hypothesis since both performance deficits and performance facilitation were observed as suggested in Table 6.

The primary support for the content interference hypothesis is found in the Rule Production X Problem Dimension X Problem Type interaction for the prediction phase data (see Figure 1). This same interaction was not significant for either the test or proof phase data. This result was somewhat disconcerting since the test phase most closely replicates the traditional Wason task procedures. For the test phase errors, there was a significant Problem Dimension X Problem Type interaction (see Figure 3) which supports the content interference predictions given in Table 6. However there was no interaction with the rule presentation condition which was predicted from the hypotheses.

A factor which was expected to have considerable influence on conditional logic problem solving was the subject's cognitive level. It was hypothesized that formal operational subjects would show differential responding across rule presentation conditions while concrete operational subjects were expected to show high error rates across all conditions. However, a Cognitive Level X Problem Dimension interaction (see Figure 2) was the only interaction involving the cognitive factor. As can be seen in the figure, the relationship was somewhat trivial in that it indicated that concrete subjects made more errors than formal subjects with greater difference in the proportion of errors for the concrete subjects between 2- and 3-dimensional problems than for the formal subjects. These data would seem to indicate a minimal amount of impact of concrete and formal operations on conditional logic problem solving, particularly with respect to content interference. This was somewhat inconsistent with the developmental data in this study which indicated a strong developmental relationship.

However, a further analysis of these data (see Table 7) suggests that there is a significant impact of cognitive level on the types of errors made, even though there was none in the number of errors. An examination of the pre-test Wason problems indicated that the formal operational subjects were making qualitatively different responses from the concrete operational subjects. From among the "solution responses" available, it is noted that (1) only formal operational subjects gave the correct ($p\bar{q}$) response and (2) among the incorrect responses they had a higher rate of selecting p. The concrete operational subjects tended to make the pq type error as well as selecting all the choices ($p\bar{p}q\bar{q}$) as solutions. Consistent with these observations, a significant chi square {$\underline{X}^2(4) = 17.68$, $\underline{p} < .01$} analysis was obtained for these data. Comparable results were found for the post-test Wason problems. These data indicate that while both groups were making errors, they differed qualitatively. The data also suggest that the formal operational subjects were making responses of a higher developmental level than the concrete subjects. In the case of the pq response, content interference appears to be present since this is the solution predicted based on a matching strategy, whereas the $p\bar{p}q\bar{q}$ response is an immature guessing response which simply opts for all alternatives. The p response, found in the formal subjects, represents a somewhat better but incomplete understanding of the logic in that these subjects realized that the q and the pq matching error was incorrect. These subjects comprehend some of the logic as indicated by the p selection and rejection of q but fail to select $\bar{q}$. Developmentally, a progression from $p\bar{p}q\bar{q}$, to pq, to p, to $p\bar{q}$ would be expected.

The notion that elements contained within a logical syllogism might interfere with reasoning processes by directing attention away from the logical form and requirements of an argument was supported. Evidence for this content interference was found in the present study in that, when content interference factors were reduced experimentally (removal of the interfering elements), performance improved. However, other results indicate that task difficulty increases the probability of content interference even when it is experimentally reduced. It should be noted that content interference does not always reduce performance; it can also facilitate such as in the case of the AN problem types. Future research might be directed toward identifying other factors which may serve as task difficulty variables. Another area of investigation might be an examination of the factors that eventually allow the subjects to overcome content interference through additional processes and thereby correctly solve the conditional logic problems even when interfering elements are present. Brainerd (1983) has suggested some connections between level of cognitive development and memory processing constraints which might mediate these kinds of changes.

The role of cognitive level on conditional logic problem solving indicates that there are differences between the kinds of errors made by concrete level subjects as compared to formal level subjects. The results suggest that while formal operational subjects are making errors in conditional logic problem solving, their errors are qualitatively different and developmentally superior to those made by the concrete operational subjects. This result has implications for the study of conditional logic problem solving in that researchers must examine not only the quantitative but also the qualitative error data.

TABLE 1

Summary of the Percentage of Card Combinations Selected in Four Experiments by Wason

Card Combinations	% Selection
p & q	46%
p	33%
p, q, & $\bar{q}$	7%
p & $\bar{q}$ (correct solution)	4%
others	10%

Note: Data from Wason & Shapiro (1971).

TABLE 2

Summary of Means for Prediction Phase Errors across Cognitive Level, Rule Presentation, Problem Dimension, and Problem Type

Cognitive Level	Rule Presentation	Number of Subjects	Problem Dimension 2: Problem Type AA	AN	NA	NN	Problem Dimension 3: Problem Type AA	AN	NA	NN
Concrete	Rule	10	0.40	0.50	2.20	1.50	1.70	0.10	3.80	3.00
	Partial	10	0.60	0.80	0.60	0.80	2.60	1.40	3.40	1.20
	No Rule	10	0.40	0.40	0.00	0.30	1.20	1.60	3.60	1.30
Formal	Rule	10	0.20	0.10	1.00	0.40	0.60	0.20	1.20	0.50
	Partial	10	0.10	0.00	0.00	0.00	0.50	0.20	1.30	0.10
	No Rule	10	0.50	0.70	0.10	0.50	0.40	0.70	4.00	1.80

TABLE 3

Summary Table of Cognitive Level X Rule Presentation X Problem Dimension X Problem Type MANOVA for Errors in the Prediction Phase

Source	df	F	
Between Subjects			
Cognitive Level (CL)	1,54	12.41	**
Rule Presentation (RP)	2,54	0.55	
CL x RP	2,54	3.00	
Within Subjects			
Problem Dimension (PD)	1,54	59.28	**
CL x PD	1,54	7.25	**
RP x PD	2,54	3.61	*
CL x RP x PD	2,54	0.43	
Problem Type (PT)	3,52	7.02	**
CL x PT	3,52	0.32	
RP x PT	6,104	2.50	*
CL x RP x PT	6,104	1.65	
PD x PT	3,52	5.57	**
CL x PD x PT	3,52	0.67	
RP x PD x PT	6,104	2.89	**
CL x RP x PD x PT	6,104	0.77	

** $p < .01$

* $p < .05$

TABLE 4

Summary Table of Cognitive Level X Rule Presentation X Problem Dimension X Problem Type MANOVA for Errors in the Test Phase

Source	df	F	
Between Subjects			
Cognitive Level (CL)	1,54	14.77	**
Rule Presentation (RP)	2,54	1.06	
CL x RP	2,54	0.18	
Within Subjects			
Problem Dimension (PD)	1,54	56.32	**
CL x PD	1,54	0.35	
RP x PD	2,54	1.71	
CL x RP x PD	2,54	0.29	
Problem Type (PT)	3,52	39.48	**
CL x PT	3,52	2.39	
RP x PT	6,104	1.71	
CL x RP x PT	6,104	0.69	
PD x PT	3,52	11.68	**
CL x PD x PT	3,52	2.08	
RP x PD x PT	6,104	0.91	
CL x RP x PD x PT	6,104	0.79	

** $p < .01$

* $p < .05$

TABLE 5

Summary of Means for Test
Phase Errors across Cognitive Level, Rule Presentation, Problem Dimension, and Problem Type

Cognitive Level	Rule Presentation	Number of Subjects	Problem Dimension 2: Problem Type AA	AN	NA	NN	Problem Dimension 3: Problem Type AA	AN	NA	NN
Concrete	Rule	10	1.30	0.90	1.80	1.30	2.40	0.60	3.40	1.50
	Partial	10	1.00	0.80	0.90	0.70	2.70	1.10	2.10	1.20
	No Rule	10	1.40	1.20	1.20	1.50	2.40	0.70	2.60	1.60
Formal	Rule	10	0.80	0.50	1.20	0.80	1.30	0.60	1.80	1.10
	Partial	10	0.80	0.30	0.40	0.40	1.50	0.80	1.90	0.80
	No Rule	10	0.90	0.90	0.50	0.40	1.30	0.30	2.50	1.00

TABLE 6

Predicted Solutions and Errors based on Content Interference for All Problem Types and Problem Dimensions

		Problem Type			
		AA	AN	NA	NN
	SAMPLE RULE	IF A THEN 1	IF A THEN NOT 1	IF NOT A THEN 1	IF NOT A THEN NOT 1
2-Dimension Problems	Correct Solution	A,2	A,1	B,2	B,1
	Predicted Content Interference Solution	A,1	A,1	A,1	A,1
	Predicted Errors:				
	OM error	1	0	2	1
	CO error	1	0	2	1
	Total	2	0	4	2
3-Dimension Problems	Correct Solution	A,2,3	A,1	B,C,2,3	B,C,1
	Predicted Content Interference Solution	A,1	A,1	A,1	A,1
	Predicted Errors:				
	OM error	2	0	4	2
	CO error	1	0	2	1
	Total	3	0	6	3

Note: OM-omission errors; CO-commission errors.

TABLE 7

Frequency of Response Type across Cognitive Level for Pre-test Wason Problem

Cognitive Level	$p\bar{q}$	p	pq	$p\bar{p}q\bar{q}$	others	
	Response Type					
CONCRETE	0	4	16	7	3	30
FORMAL	9	11	8	1	1	30
	9	15	24	8	4	60

$X^2(4) = 17.86 \quad p < .01$

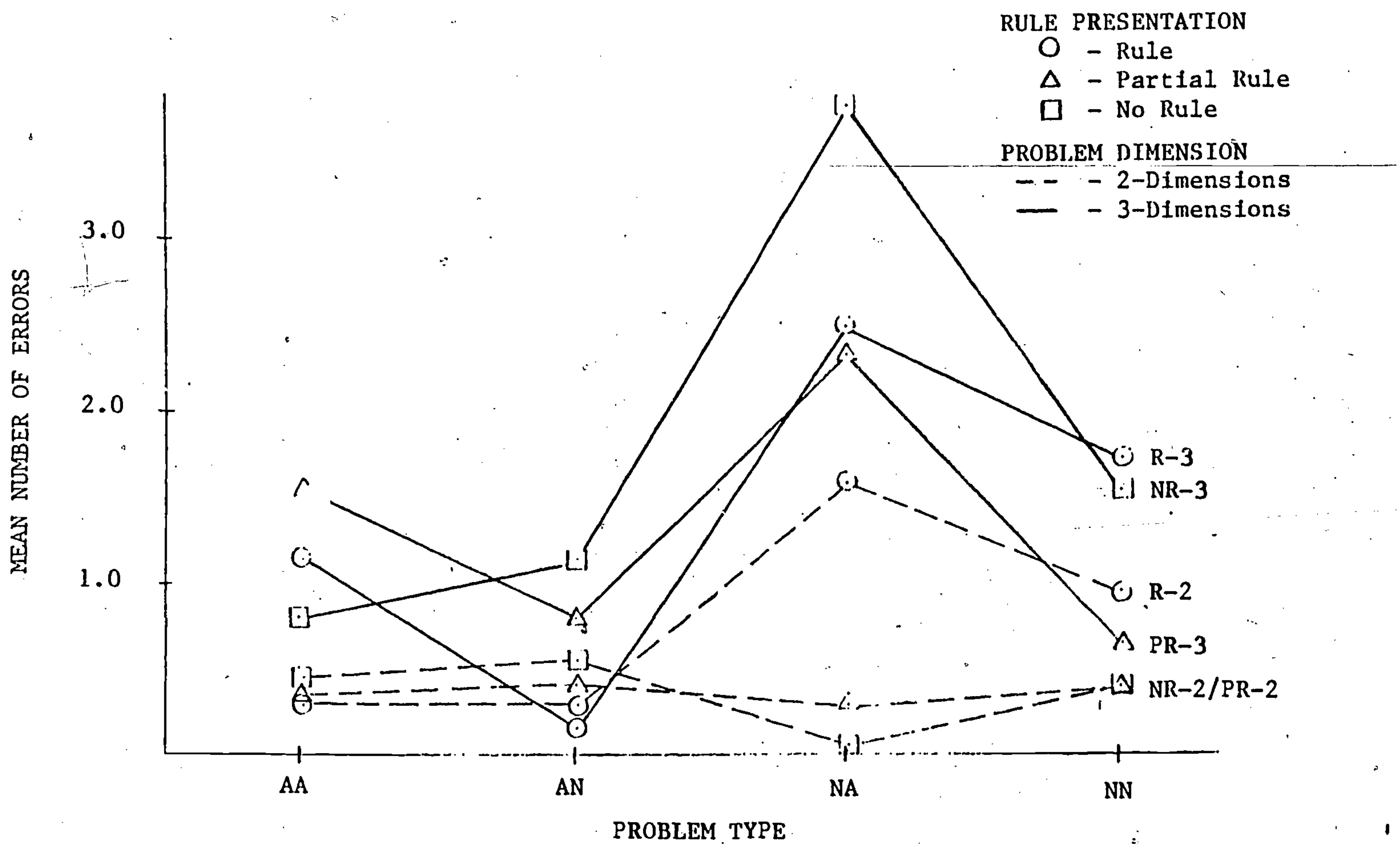


Figure 1. Mean number of errors in prediction phase for rule presentation conditions as a function of problem dimension and problem type (AA - If p then q, AN - If p then $\bar{q}$, NA - If $\bar{p}$ then q, & NN - If $\bar{p}$ then $\bar{q}$).

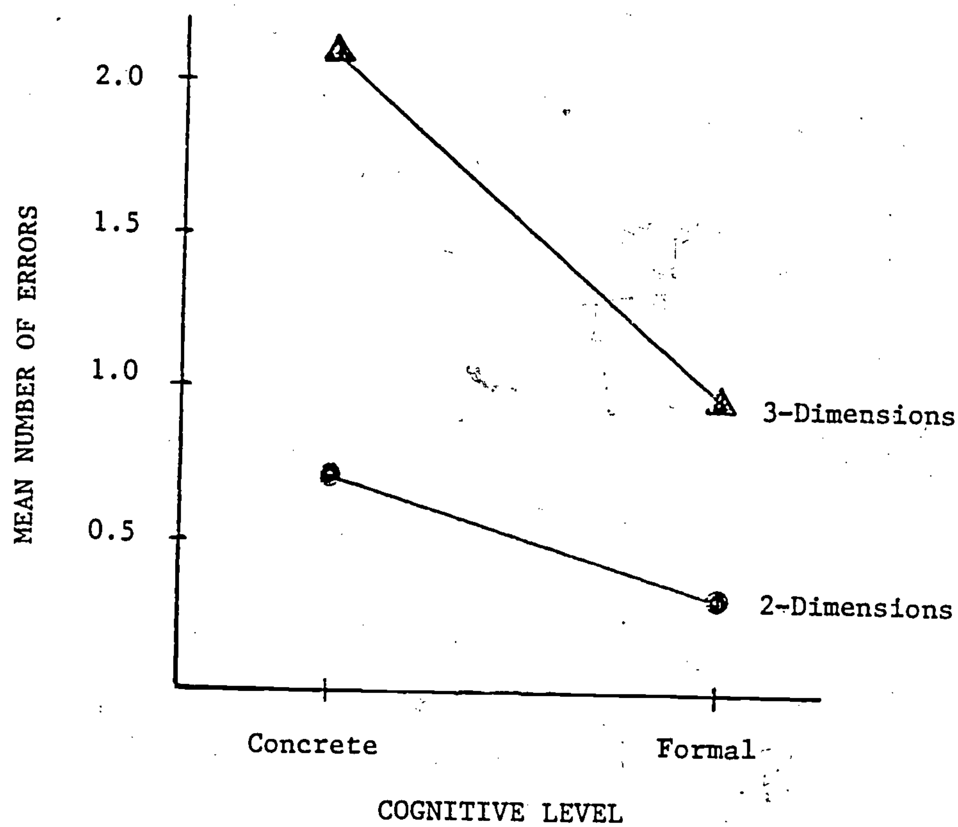
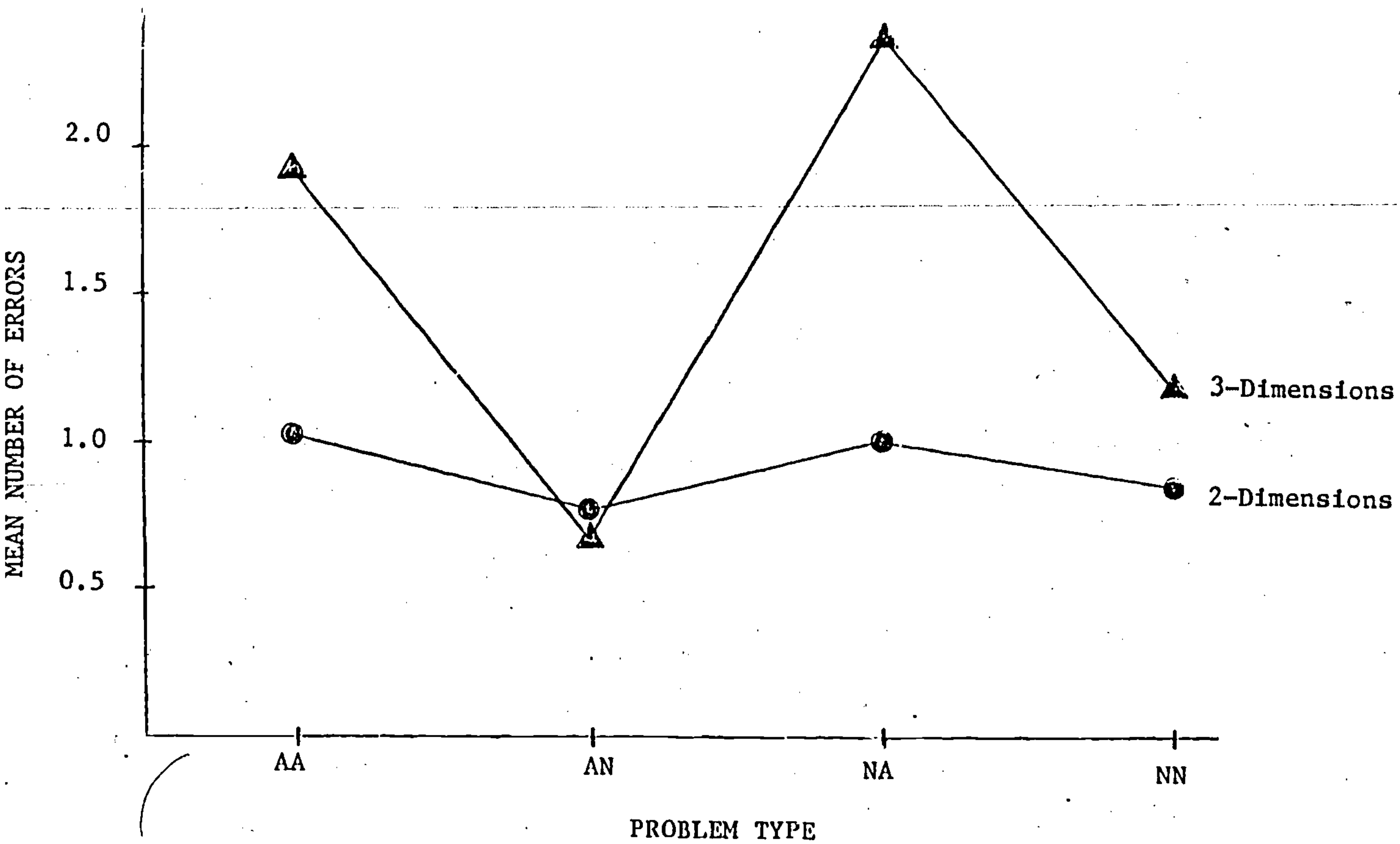


Figure 2. Mean number of errors in the prediction phase for problem dimensionality as a function of cognitive level.



gure 3. Mean number of errors in the test phase for problem dimensionality as a function of problem type (AA - If p then q, AN - If p then $\bar{q}$, NA - If $\bar{p}$ then q, and NN - If $\bar{p}$ then $\bar{q}$).

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