CONDITIONAL SYLLOGISTIC REASONING

AND WORKING MEMORY CAPACITY

by

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ABSTRACT

A relationship between working memory capacity and propositional reasoning abilities is examined within the framework of Marcus & Rips (1979) verification model of conditional syllogisms and the mental operator model of cognitive development proposed by Pascual-Leone (1970). Using the four-stage verification model to explain required cognitive processes, it is argued that development in the ability to solve conditional syllogisms can be attributed, in part, to an epigenetically determined increase in working memory capacity. With a sample composed of 77 pre-adolescent and university students, micro-computers presented individual subjects with two 40-item conditional syllogistic reasoning (CSR) tasks and a backward digit span (BDS) task, in two sessions.

The results are not as predicted. Indexing memory capacity by BDS, analyses of covariance and polynomial regression analysis, fail to identify a relationship with correct CSR responses. While grade is shown to explain a major percentage of variance in CSR scores, knowledge of the conditional rule is also identified as an important factor. Arguments are grouped according to order of difficulty and validating response time, and the results of subjects identified as knowing the conditional rule fail to agree with the groupings predicted by the Marcus & Rips model while supporting development of a single operative scheme for conditional syllogistic reasoning.

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I. STATEMENTS OF PROBLEMS AND HYPOTHESES

Introduction

The purpose of the study was to investigate a relationship between pre-adolescent and college students' propositional reasoning abilities and working memory capacity. Specifically, the present study explored the possibility of explaining developmental findings in conditional syllogistic reasoning, indicated in studies by Paris (1973), Taplin, Staudenmayer & Taddonio (1974), and Sternberg (1979), in terms of epigenetic growth in the capacity of working memory. Pascual-Leone's (1970) Mental Operator model of cognitive development, which had previously been demonstrated as having a relationship between working memory capacity and Piagetian cognitive substages, provided a theoretical framework. A theoretical basis for the processing of conditional syllogisms was found in the four-stage model proposed by Marcus & Rips (1979).

Conditional Syllogistic Reasoning

In a propositional statement, an antecedent premise such as "If you eat your dinner", is combined with a consequent premise, such as "then you may have dessert", to imply a unidirectional causal relationship between the two. To act in a rational manner, according to what is implied in the propositional statement, a child must understand the meaning of the conditionality, and deduce an appropriate conclusion from the premises. An empirical investigation of a conditional syllogistic deductive reasoning problem first present an "if, then" premise, expressed symbolically as $P \rightarrow Q$. A second premise is subsequently presented that affirms or denies either the antecedent or the consequent. Thus, four arguments can be defined, as follows:

1. Affirming the antecedent (Modus ponens)
2. Denying the antecedent (Modus tollendo tollens)
3. Affirming the consequent
4. Denying the consequent

For each syllogistic argument, the conclusion may be either affirmative or negative, resulting in a total of eight different argument forms. The subject is asked to evaluate the validity of the conclusion based on information derived from the first and second premise. Typically, the syllogisms are of the form[1]:

If there is a p, then there is a q

There is a p

There is a q

Developmental Trends in Conditional Reasoning

A developmental trend in comprehension of language connectives has been clearly established. In his study with grades two, five, eight and eleven, Paris (1973) identified two patterns of comprehension evident with age, including the increased differentiation of conjunctive from disjunctive propositions, and the causal interpretation of biconditional and conditional sentences. He showed that in interpreting causality, younger subjects tended to judge a complete proposition as false if any part of the syllogism, antecedent or consequent, was false. The responses of subjects changed with age, however, suggesting search for a causal relationship between premises and one event's dependence on a second event.

The findings of Taplin, Staudenmayer & Taddonio (1974) supported those of Paris in suggesting that comprehension of the causal relationship of the conditional connective "if p, then q", was the most difficult, and involved an intermediary stage of biconditionality. In this transition stage, the child comprehended a relationship with reversible causality between the two premises, whereby neither were exclusively antecedent nor consequent. As a result, P implied Q and Q implied P; this relationship may be symbolically represented as $P \leftrightarrow Q$.

Taplin et al's (1974) investigation of developmental changes in conditional reasoning, with subjects from grades three, five, seven, nine and eleven, indicated that there was improved performance on a conditional reasoning task with age. Their results also indicated that the degree of improved performance was more evident in some argument forms than others.

Sternberg (1979) studied developmental patterns for logical connectives, and examined the relative importance of logical and linguistic processes in this development. Using a form of componential analysis, a technique different from that used by Taplin et al, he compiled data that generally supported the previous findings. Looking at both linguistic encoding and logical combination, he confirmed that the conditional logical connective was the most difficult and supported a developmental trend. His data indicated that in encoding tasks, grade two children evidenced conjunctive and disjunctive interpretations of the conditional, while performance of those in grades four, six and eight suggested a biconditional interpretation. With some evidence of the correct conditional interpretation beginning at grade eight, it was not until high school and college age that this interpretation was strongly in evidence. Sternberg inferred from the data that the logical combination of premises followed the same general developmental trend as linguistic encoding, but lagged by about two years.

Verification Model of Conditional Syllogisms

In developing a process model of conditional syllogistic reasoning, Marcus & Rips (1979) appear to have assumed that individuals already knew an underlying conditional 'rule' or scheme. The information processing model developed by these authors consisted of four stages, and relied on both 'structural' and 'error' assumptions; the former comprising an information processing sequence underlying correct reasoning while the latter considered explanations of erroneous reasoning.

The model makes a number of predictions about response latencies for validity decisions of each of the eight argument forms. These predictions assume that while some syllogistic arguments require two stages of processing, others require three and four. The investigators supported their prediction that arguments formed three response latency (RT) groups, depending on the number of processing stages required. They noted that RT increased as syllogisms increased in the number of negations, a result also reported by Lee (1984).

According to Marcus & Rips (1979), [p,q] and [p, Not-q] syllogisms are processed through only the first two stages of the model, 'Encoding Premises and Conclusions' and 'Does Second Premise Equal First Premise?', and form the first cluster of arguments. The remaining six arguments proceed for further processing in the third stage, 'Is Conclusion Consistent with First and Second Premises?' This stage uniquely identifies the [Not-q, p] syllogism as requiring a Never True response. Requiring three processing stages, this single argument forms a second 'cluster'. The remaining five syllogisms all require the fourth processing stage and thereby form a third cluster. Identified as Always True at this stage is the syllogism [Not-q, Not-p], in which the negating of the conclusion produces a doubly negated proposition inconsistent with the conditional. The remaining syllogisms, despite negated conclusions, are consistent with the premises and are concluded to be Sometimes True. Figure 1, which schematically reproduces the Marcus & Rips model, identifies the three clusters of syllogisms by the stage in processing at which a conclusion can be drawn and the appropriate response prepared.

INSERT FIGURE 1 ABOUT HERE

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In addition to the above structural elements, the model takes into account three potential sources of error. According to Marcus & Rips, the source of most probable error is the premature termination of processing; hence an inference error could occur with termination of processing after any of the first three stages indicated above. As pointed out by Marcus & Rips, the model considers the psychological meaning of logical connectives which does not correspond entirely to the propositional logic. Errors may also result from the processing of negative premises or conclusions during stages three and four, or from the reversal of the P-Q sequence.

Theoretic Role of Working Memory

Implicit in the Marcus & Rips model is the assumption that the cognitive processes involved in comprehending, analyzing and reaching a conclusion about a problem in conditional reasoning occur in working memory. Viewed in the information processing paradigm, the cognitive processes involved in attaining a logically valid conclusion for a conditional proposition necessitate a minimum capacity in working memory, a capacity that appears to undergo developmental change (Pascual-Leone, 1970). From this implication, a potential explanation of the developmental trend noted in syllogistic reasoning may be advanced: that the ability to successfully solve a syllogistic reasoning problem is contingent on the working memory requirements of the problem and the available working memory capacity in the individual.

Investigations into Development in Working Memory Capacity

The development of working memory capacity was explored by Pascual-Leone (1970) who proposed a neo-Piagetian model. This model postulated a quantitative parameter to account for Piaget's qualitative description of intellectual development. According to Piaget (cf. 1958), the integration of information occurs in a 'field of centration' or 'field of equilibrium and that this field increases in size with age. Pascual-Leone attempted to quantify the increasing size of this 'field' and to relate it to the Piagetian construct of intellectual development. In his subsequent investigation, Case (1972) demonstrated that the Pascual-Leone model could be validated by a different measure, and added support to the Mental Operator as the set measure of 'field of centration' or 'M-space'.

In validating the neo-Piagetian construct, Case (1972) used a digit insertion technique by which subjects were required to locate a target digit within a previously presented series of digits. He noted, however, that the Backward Digit Span (BDS) task yielded identical norms to those obtained with the digit insertion technique. It was suggested that the transformation of digit order required by the BDS task interfered with rehearsal and 'chunking' strategies, and thereby equated it with the cognitive processing requirements of the digit insertion task.

According to Case (1972, p. 287), what was measured in the digit insertion task, and by implication in the BDS task, was the "maximum number of activated schemes which (could) be coordinated at any one time." It can be inferred from this definition that Piaget's 'field of centration' and Pascual-Leone's 'M-space' are functionally synonymous with working memory and similar to the Short Term Store of Atkinson and Shiffren (1968).

As indicated by Pascual-Leone (1970), the growth in M-space, or working memory, is considered to be linear, and determined primarily by epigenetic factors. Occurring generally between the ages of three and sixteen years, the modal value of M-space increases from a + 1 to a + 7, and can be related to Piagetian substages.

In the notation used to indicate working memory capacity, k represents the number of activated schemes that can be attended to and manipulated at a given developmental stage, while a represents the working memory capacity requirements of the schemes that direct and coordinate the manipulation. By 'scheme' is meant an "original set of reactions ... susceptible to being transferred from one situation to another by assimilation of the second to the first," (Pascual-Leone, 1970, p. 306). They share common features, such as being recursive, definable by their content (i.e., perceptual, cognitive, etc.), and form three general groups, identified as superordinate, figurative and operative.

Superordinate schemes are the overall plans activated to consider a specific problem situation. Similar to a computer program that uses subroutines, these 'executive' schemes are internal representations of procedures appropriate for attaining particular objectives. The second type, figurative schemes, are capable of releasing responses of superordinate schemes; that is, they are internal representations of known or recognizable elements of information and correspond to 'chunks' (Miller, 1956). Finally, there are operative schemes which are internal representations of functions or rules applied to figurative schemes to generate transformations.

According to these definitions, *a* includes the working memory requirement for the superordinate and operative schemes, and *k* includes the working memory requirement of the figurative schemes to be manipulated. In view of the additive relationship between *a* and *k* in deriving memory capacity, and the maximum representational capacity of working memory or *k*, at a given age, these factors appear to be important in establishing the level of intellectual functioning.

Underlying the Pascual-Leone construct is the notion that *a* remains constant across age groups for a specific, well-learned task. Here, superordinate and operative schemes associated with a given task tend to become well-established in the individual. At the point at which the task is thoroughly, or 'overly' learned, the working memory requirement of these schemes, *a*, attains a task-related minimum that remains constant in any subsequent performance of the same task. It should be noted, however, that the value of *a* across different tasks can vary and will depend upon the complexity and amount of transformation and coordination required.

Implicit in the Pascual-Leone proposal is that the working memory theoretically available to retain the figurative schemes is the capacity remaining in the epigenetically determined M-space after the executive and operative schemes have been accommodated. This suggests that working memory assigned to *a* or *k* is interchangeable, and is governed by the demands of the task and overall capacity. The BDS task can be used to illustrate this interchangeability and the task-related constancy of *a*.

Briefly, in a BDS task the subject is sequentially shown a series of two-to-nine digits. With no external memory aid, their task is to recall the digit series in the reverse order of presentation. To accomplish this, the subject must retain the individual digits in memory, and then manipulate them into the required reverse order and recite this sequence back to the experimenter. This manipulation and coordination function, that is, the backward transformation, is assumed to be governed by task appropriate superordinate and operative schemes which require a portion of working memory; this working memory requirement is equivalent to _a_, and assumed to be constant once the BDS task is well-learned.

It is also assumed (Case, 1972) that the nature of the BDS task keeps the subjects from 'chunking' digits together and thereby implies that each digit is equivalent to a single figurative scheme. The span of digits that a subject is capable of recalling in a reverse order therefore indexes the number of figurative schemes that they can manipulate for the BDS task; this span is considered to be an indirect measure of _k_.

It becomes apparent that for any given overlearned task then, _a_ and _k_ should have unique values, but in no case may _a_ + _k_ exceed the epigenetically determined maximum capacity of working memory. This suggests that, where a task requires more capacity than an individual has available, that task should not be successfully performed.

As summarized by Case (1972), it should be noted that _a_ and _k_ do not account for all variables of cognitive performance in terms of variation in working memory. Also important is the proportion of working memory devoted to a particular task and the repertoire of schemes available to the individual, particularly as influenced by learning factors and field factors that govern what schemes are to be activated.

Working Memory Capacity and the Verification Model

The notion of figurative and operative schemes may be applied to the model of Marcus & Rips, where different working memory requirements may be inferred. As indicated by the author's model, the number of processing stages through which each argument passes directly affects the amount of processing time required. The processing stages may be considered equivalent to three operative schemes, implying three working memory levels ($\underline{a}', \underline{a}'', \underline{a}'''$). Each level represents one of the three argument groupings as defined by the model and supported by RT observed by Marcus & Rips (1979). These researchers also suggested that processing stages were not the only determinant of response latency. They also incorporated into their model factors for the negation of premises, and the reversal of premises in four of the arguments (Types: [q,p], [q, Not-p], [Not-q,p], [Not-q, Not-p]).

Summary and Hypothesis

There is evidence to suggest that working memory capacity is not fixed, but increases as the child develops (Pascual-Leone, 1970; Case, 1972, 1974). Hence, it is proposed that the ability of a subject to successfully solve a syllogistic reasoning problem should be affected by the working memory capacity available at a particular point in development. Specifically, it was hypothesized that the ability of subjects to solve each of the eight syllogistic arguments, according to the conditional truth function, will depend on their working memory capacity as defined by backward digit span.

The present study attempted to identify relative working memory capacity, as inferred from BDS scores, required to successfully solve syllogistic arguments, giving consideration to the allocation of memory between operative and figurative schemes. Subjects were presented with a series of concrete and abstract syllogisms, and their working memory capacity determined using a BDS task. In the present study, the premises involved in a syllogistic proposition were considered to be equivalent to figurative schemes. This view supplemented that of Marcus & Rips (1979) and provided additional explanation for the response latencies predicted. By this view, each positively stated premise, or more specifically, the subject of that premise, was assumed to represent one figurative scheme and correspond to a _k_ value of one. In the most common of arguments, [p,q], two positively stated premises are involved and represented the least number of figurative schemes to be manipulated in solving a syllogistic problem. In this case, it was reasoned that _k_ took on a value of two. Negation or reversal of premises required additional manipulation of figurative schemes, and resulted in additional processing time.

It must be noted that the verification model identified the encoding of premises and conclusions as a separate stage from processing arguments. However, the experimental methodology of Marcus & Rips did not make this distinction; RT was measured from onset of the complete syllogism to validating response. Implicit in this methodology and the resulting analysis, is that encoding should be constant across argument types. Such an assumption is open to question. There exists strong support for encoding being the source of different levels of difficulty in solving each of the eight syllogisms (Sternberg, 1979; Taplin _et al_, 1974). To emphasize the evaluating process, the current study measured validating time (VT) from onset of the conclusion to validating response; this procedure reduced, but did not eliminate measurement of encoding time, restricting it to the encoding of the conclusion.

With the exception of RT measurement, the current study replicated Experiment 2 of Marcus & Rips (1979), and attempted to determine if the verification model is consistent with the performance of subjects classified as knowing the conditional rule. If the model were to be supported, VT of subjects with a mastery of the conditional rule should increase according to the complexity of processing required. In addition, the level of difficulty, as measured by the number of overall correct responses, should also increase with the number of processing stages proposed by the model. Both VT and number of correct responses should separate arguments into three similar groups corresponding to the three levels of operative scheme memory capacity, $\underline{a}'$, $\underline{a}''$, and $\underline{a}'''$, at least for those subjects who can be regarded as knowing the logic rule.

II. METHOD

Subjects and Design

Initially, a total of 92 subjects was identified, of whom 31 were drawn from each of grades five and seven, and 30 from paid undergraduate and graduate university students. Elementary students were selected from a school in the Lower Mainland of British Columbia; the university subjects were drawn from students at the University of British Columbia. Upon obtaining the participants' consents through the school and university instructors, a total of 77 subjects remained in the sample for the present experiment. The sample consisted of three groups, 25 grade five, 27 grade seven and 27 college students.

As results of previous studies (Taplin, Staudenmayer & Taddonio, 1974; Sternberg, 1979) had identified little evidence of conditional syllogistic reasoning below grade five, the youngest subjects for the current study were selected from this grade level. Based on the investigation of Pascual-Leone (1970), it was determined that these younger subjects could be expected to have a modal M-space value of a + 4 to a + 5. To provide subjects with a range in modal M-space values to a + 7, the maximum identified by Pascual-Leone, grade seven and university students were also selected. With testing occurring at the end of the school year, grades five and seven subjects were assumed to correspond to the Late Concrete and Early-Middle Formal Piagetian substages, respectively; college subjects were assumed to correspond to Late Formal and beyond.

Equipment and Materials

The two tasks, Backward Digit Span and Conditional Syllogistic Reasoning, were both presented individually to subjects using a micro-computer; this equipment automatically recorded item responses and validating response latency. Six systems were used, each consisting of an Apple IIE micro-computer, a 12-inch monochrome monitor, and two disk drives; one drive was used to run the program and the second to record the data. Each system was so arranged as to prevent subjects from seeing a screen other than their own.

In the BDS task, eight digit spans were evaluated twice; spans tested were from two through nine digits. The sequences and order of digit span length were determined randomly from Random Number Tables (Edwards, 1968); consecutive duplicate and sequentially ordered digits in any span were eliminated. The selected spans are presented in Appendix B. A random presentation of target spans was selected to avoid a response set, theoretically consistent with the established BDS testing paradigm.

The conditional syllogism reasoning (CSR) task consisted of the same eighty items used by Lee (1984). Briefly stated, these syllogisms were the result of ten semantic situations, two abstract and eight concrete, in a factorial combination with the eight argument forms previously described and summarized in Appendix A. The syllogisms comprised three statements or propositions, including a major premise, a minor premise, and a conclusion.

Procedure

Subjects were tested in groups of six, in two 30-45 minute periods. The same experimenter administered all sessions for grades five and seven subjects, assisted by a female graduate student; this assistant tested all university subjects. During the first test sessions, subjects received forty CSR problems; during the second session, they received the BDS task and the second set of forty CSR problems. Each subject's first test session began with a brief introduction to acquaint participants with the experiment and to confirm that participants were sufficiently familiar with the computer keyboard to accomplish the proposed tasks (Appendix C).

The tasks were self-timed, with presentation of all materials computer-controlled according to duplicate programs copied from a common master. Each task was preceded by specific instructions presented on the computer screen pertaining to the task. Presented first was the BDS task (Appendix D)

Following the instructions, the first practice digit span sequence began, starting with the word 'READY', shown for 1.2 seconds. The screen then went blank for 1.2 seconds before the first digit appeared; each digit was presented individually in the centre of the screen for 1.2 seconds. At the end of the first practice series only, the subject was reminded of specific instructions.

... First practice series ...

> Now, please indicate the digits you have just seen in backwards order. Remember, if you cannot think of a digit, put an '-' in its place.

These instructions remained on the screen for five seconds. The subject had a maximum time limit for responding of fifteen seconds; responses were not displayed on the screen. At the end of each digit span sequence, the screen became blank for five seconds and then the next sequence began with the word, 'READY.' After the four pertaining problems, subjects were told they had completed the four practice problems and to proceed to the actual task. The experimental task was identical to the practice session, but excluded all instructions.

At the conclusion of the BDS task, the screen became blank for fifteen seconds while the computer loaded the CSR program; the instructions for the next task were then displayed (Appendix E).

Following the instructions, the first argument appeared on the screen, beginning with the first proposition which appeared on the screen for five seconds:

Item 1:
Suppose that you know that, (first proposition),

The screen then went blank for 1.2 seconds, until the second proposition was shown:

and (second proposition)

This proposition was also displayed for five seconds, when the screen again went blank for 1.2 seconds and the conclusion was displayed:

Then would this be true? (Conclusion)

After five seconds, the multiple choice answers appeared:

Always true: A
Sometimes true: S
Never true: N

Once answered, corrective feedback was presented. At the end of each problem sequence, the screen went blank while the computer recorded the subject's response and validation response time (VT) recorded up to one millisecond on the diskette. Subjects were presented with the same instructions before the second set of forty CSR problems when tested a few days later.

III. RESULTS

Initial processing of data from individual subjects resulted in a set of three measurements, including backward digit span and two conditional syllogistic reasoning scores, number of correct responses, and associated validating time for individual requirements. BDS was established as the longest span answered correctly by subjects in both span replications. Five subjects failed to attain the criterion; BDS was estimated for these subjects based on the overall number of digits in the correct relative position. The raw number of correct CSR responses for each of the eight arguments was determined for each of the two presentations of the task. Each task consisted of eight arguments individually presented five times, permitting a maximum score per task of five for each argument. These data are summarized in Table 1. A further CSR datum, VT, was measured from onset of the argument's conclusion to making the correct response.

INSERT TABLE 1 ABOUT HERE

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Analysis of CSR Test Responses

To determine the effect of knowledge of the conditional rule on CSR performance, subjects were classified into one of two groups, mastery and non-mastery. Mastery-level subjects were determined from results of the first CSR task, according to a method originally proposed by Lee (1984), in which a score of four or greater was required on at least six of each eight arguments. Sixteen of the 77 subjects met this criterion, including two in Grade 5, two in Grade 7, and twelve at college level.

Under the premise that conditional syllogistic reasoning resembled the verification model proposed by Marcus & Rips (1979), the analysis had two purposes: to determine (1) the effect of working memory capacity on CSR problems, and (2) the extent to which predictive performance of the model could be explained by knowledge of the conditional rule implicitly assumed by Marcus & Rips (1979).

To determine the influence of working memory capacity on conditional syllogistic problems, a series of analyses of covariance were performed on the number of correct responses and VT of individual arguments. BDS and mastery were used as covariants, with grade the grouping factor. The results were not as predicted. In no argument did BDS exceed the chance level, while mastery was a significant factor in all arguments, and grade in six. BDS was also tested in a polynomial regression analysis, which also failed to identify any effect of working memory capacity.

INSERT TABLE 2 ABOUT HERE

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To examine further the findings of the analysis of covariance, a determination was made of the percent of variance of correct argument responses accounted for by each of three predictors: grade level, BDS, and mastery of the conditional rule. In all but one argument, [Not-p, Not-q], the majority of variance attributed to the three factors was explained by grade level, accounting for between 3.3% and 29.8% of variance, with a mean of 15%. While grade level explained only 5.4% of the variance on argument [Not-p, Not-q], mastery level accounted for 12.1%, the most variance explained for by this factor on any of the arguments; with a mean of 6.8%, mastery accounted for 2.1% to 12.1% of variance. By contrast, BDS, with a range of 0% to 2.2% and a mean of 0.9%, explained little. The analysis was repeated on the total score of all eight arguments from the second CSR task, to determine the effect of the three factors on the overall response pattern. The analysis supported the findings for individual arguments by identifying grade as explaining the majority of variance at 32.1%, and mastery as the second factor, explaining 17.8% of variance. As in the previous analysis, BDS accounted for only 1.1% of variance.

Clearly, the results failed to support the hypothesis by identifying no argument in which BDS accounted in any significant way for performance on the CSR task. This finding suggests that development in working memory capacity has little effect on cognitive abilities, as defined by the conditional reasoning problem. In view of the importance of grade level to CSR performance, it must be inferred that other developmental factors contributing to improved performance on this task with age, remain to be identified. In addition, factors other than grade and master level appear to be involved, as the majority of variance on all arguments remains unexplained.

Analysis of Performance on Eight Types of Arguments by Mastery Level

To examine whether the order of argument difficulty was consistent with that predicted by apparent working memory requirements of the Marcus & Rips (1979) model, repeated measures analyses of variance were performed on combined results of the two CSR presentations. As mastery of the conditional rule was implicitly assumed in the verification model, data for mastery and non-mastery subjects were analyzed separately.

Initial analyses across all eight arguments, for each group, found that arguments varied in difficulty, according to the number of correct responses and in VT. Further analysis, with repeated measures analyses of variance across pairs of arguments, identified the rank order of arguments indicated in Table 3.

INSERT TABLE 3 ABOUT HERE

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The analyses revealed different orders of argument difficulty for each mastery level on each CSR datum. Further, and as predicted by the Marcus & Rips (1979) model, arguments could be grouped into clusters of similar difficulty. However, the order of difficulty in neither mastery level group was as expected from the model. Those subjects classified as possessing the conditional rule evidenced fewer argument clusters than non-mastery subjects in both correct responses and VT. This reduction in the number of clusters, from four to two, with improved performance where one of the clusters for mastery subjects represented seven of the eight arguments, suggests a developmental trend towards a single VT cluster.

Comparison of Present Data with the Reported Data

To test external validity, an analysis was conducted on data from the conditional syllogistic reasoning task to permit comparison with findings reported by Taplin & Staudenmayer (1973) and Taplin, Staudenmayer & Taddonio (1974). Results of all three experiments are summarized in Table 4. While some differences are noted on specific arguments, particularly for grade 5 subjects, there appears a similar overall grade-related trend.

INSERT TABLE 4 ABOUT HERE

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A further comparison was made with results reported by Sternberg (1979) on the percent of correct conditional sets; that is, the number of sets of eight consecutive arguments in a single series as a percentage of the total number of sets. The results are very similar. In the current study, the percent of correct sets was 3.2%, 3.6%, and 12.6% for grades five, seven and college, respectively, compared to 3% for grade six and 19.0% for college subjects reported by Sternberg.

IV. DISCUSSION AND CONCLUSION

The study found little support for the central hypothesis, nor for the model of conditional syllogistic reasoning, as proposed by Marcus & Rips (1979). However, support was found for variation in argument difficulty somewhat different from that predicted by the verification model.

While it was argued that development in working memory capacity could contribute to the age-related improvement in CSR performance noted by previous investigators such as Paris (1973), this was not the case. In the current study, grade level was identified as a major factor in CSR performance with little relationship to BDS.

As discussed by Lee (1984), the conditional truth function is frequently implicitly assumed in studies of conditional syllogistic reasoning. In the current study, those subjects appearing to know the conditional rule were explicitly identified by their results on one of the two CSR tasks. Performance on the CSR task by mastery and non-mastery groups varied very significantly, ($F(1,75) = 124.5$, $p < 0.01$).

Once available to the subject, the conditional rule appears to be stable and a good predicter of performance on the second CSR task. It can be inferred, then, that knowledge of the conditional truth function, or the ability to activate the appropriate operative schemes, may be a better explanation of success in answering syllogisms than working memory capacity.

Before dismissing the working memory capacity hypothesis, the validity of the Backward Digit Span task, as used in the current study, must be questioned. The computerized task varied from standard testing approach in presenting all subjects with a random order of span lengths. In the typical

BDS task, subjects are individually presented with spans of increasing length until they fail to correctly respond to a span of specific length. In the computerized task, subjects could attain a high BDS, such as six, while failing shorter spans; this situation is not possible with the standard testing paradigm.

Viewed from the information processing paradigm, the VT data of the mastery subjects suggests that a single operative scheme may be involved in the CSR task. This operative scheme appears to develop in stages and may result from the gradual integration of at least one other scheme; a review of data from non-mastery subjects indicates that arguments may be separated into four VT clusters, while only two clusters were evident for mastery subjects.

The availability of a functional conditional rule, or conditional operative scheme, may help to account for the lack of agreement between the current data and the Marcus & Rips (1979) model. The three argument clusters predicted from the model failed to appear through either the number of correct responses or VT, suggesting that argument difficulty may not be explained by processing failure at selected stages within the model, as its authors proposed. Rather, the explanation may be a lack of a single, integrated process or conditional truth function, with the Marcus & Rips (1979) findings resulting from a collective developmental trend in the acquisition of the conditional rule present in their college-age subjects.

Caution must be used in interpreting the VT data for some non-mastery subjects where very low VT and high risk error rates on three arguments suggests that these individuals may have been guessing. As these three arguments, [q,p], [not-q, p], and [not-q, not-p], were also found to be the most difficult by non-mastery subjects, guessing may have resulted from minimal development of appropriate processing ability for these syllogisms.

Interestingly, VT's representing clusters 2 and 3 in data from non-mastery subjects which correspond with two of the easier syllogisms for this group, are somewhat lower than VT on similar arguments by mastery subjects. For syllogism [p,q], it is possible that non-mastery subjects viewed the argument conjunctively. Such an interpretation is consistent with findings reported by such previous authors as Paris (1973), Taplin (1973), and Staudenmayer & Bourne (1977), where frequent exposure to the conjunctive in early development can be reasoned to result in a separate operative scheme (Marcus & Rips, 1979). The data suggests that, in the developmental process, as the CSR operative scheme adapts to respond to more varied syllogisms, it integrates the conjunctive scheme.

While the study did not support working memory as being an important variable in the development towards conditional syllogistic reasoning, it did support development towards a single CSR operative scheme. The encoding-evaluation issue investigated by Sternberg (1979), clearly determined the primacy of encoding in the overall development of CSR processing. The current work assists in our understanding of the two year lag in attainment of the evaluation subprocess noted by Sternberg. Further, it provides evidence that younger subjects are able to accomplish complex problem solving such as conditional syllogistic reasoning, once the appropriate scheme is available to them. The challenge for education is to assist the child in building these appropriate schemes.

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FOOTNOTES

1 As this paper will refer to each of the eight arguments individually, it will be done by placing a square bracket around the second premise and conclusion; a negated premise or conclusion will be indicated by "Not-." As an example, the notation for the modus ponens argument above, is [p,q]. All eight arguments are illustrated in Appendix A, which includes the notation used throughout this paper.

TABLE 1(a)

Mean Backward Digit Spans and Mean Number of Correct Responses for Each Conditional Argument Type by Grades (N = 77)

		Grade 5 (N = 25)	Grade 7 (N = 25)	College (N = 27)
BDS	Mean	4.40	4.68	4.93
	S.D. (Range)	1.66 (2-8)	1.28 (2-7)	1.98 (2-9)
CSR Set 1				
[p, q]	Mean	3.04	4.00	4.63
	S.D.	(1.27)	(1.00)	(1.01)
[p, Not-q]		2.00	2.40	4.48
		(1.58)	(1.35)	(1.01)
[Not-p, q)		2.68	3.32	3.85
		(1.28)	(1.18)	(1.20)
[Not-p, Not-q]		3.44	2.48	3.56
		(1.23)	(1.50)	(1.34)
[q, p]		2.08	1.84	2.81
		(1.44)	(1.52)	(1.62)
[q, Not-p]		3.00	2.88	3.81
		(1.19)	(1.42)	(1.15)
[Not-q, p]		1.84	2.24	3.48
		(1.28)	(1.39)	(1.34)
[Not-q, Not-p]		1.20	2.24	2.59
		(1.29)	(1.39)	(1.37)

TABLE 1(b)

Mean Backward Digit Spans and Mean Number of Correct Responses for Each Conditional Argument Type by Grades (N = 77)

		Grade 5 (N = 25)	Grade 7 (N = 25)	College (N = 27)
BDS	Mean	4.40	4.68	4.93
	S.D. (Range)	1.66 (2-8)	1.28 (2-7)	1.98 (2-9)
CSR Set 2				
[p, q]	Mean	3.00	3.68	4.22
	S.D.	(1.23)	(1.11)	(0.85)
[p, Not-q]		2.28	3.28	4.11
		(1.31)	(1.40)	(0.85)
[Not-p, q]		2.28	2.76	3.37
		(1.40)	(1.17)	(1.33)
[Not-p, Not-q]		2.76	2.72	3.41
		(1.36)	(1.43)	(1.31)
[q, p]		1.80	1.32	2.59
		(1.15)	(1.11)	(1.42)
[q, Not-p]		2.48	2.20	2.85
		(1.42)	(1.26)	(1.70)
[Not-q, p]		1.88	2.48	3.37
		(0.88)	(1.19)	(1.42)
[Not-q, Not-p]		1.08	1.60	2.41
		(1.22)	(1.32)	(1.55)

TABLE 2

Analyses of Covariance of the Number of Correct Responses for Each CSR Argument Type of Set 2 by Grade, with Students' BDS and Mastery Level of Conditional Rule Based on CSR Set 1 (N = 77; Mastery N = 16, Non-mastery N = 61)

Argument Type of CSR Set 2	Effect of Grade F(2,72)	P	BDS Regression Coefficient	t	P	Mastery Level Regression Coefficient	t	P
[p, q]	9.18	0.01	0.10	-1.30	0.20	0.95	2.73	0.01
[p, Not-q]	19.69	0.01	0.12	1.54	0.13	1.18	3.31	0.01
[Not-p, q]	5.17	0.06	0.94	0.10	0.92	1.29	3.08	0.01
[Not-p, Not-q]	2.34	0.10	0.80	-0.81	0.42	1.42	3.22	0.01
[q, p]	7.56	0.01	0.37	0.41	0.68	0.96	2.37	0.02
[q, Not-p]	1.34	0.26	0.15	1.34	0.18	0.64	1.32	0.19
[Not-q, p]	12.40	0.01	0.15	1.85	0.07	0.96	2.61	0.11
[Not-q, Not-p]	6.41	0.05	0.01	0.07	0.95	0.93	2.03	0.05
All Arguments	535.95	0.01	0.44	1.30	0.20	8.31	5.23	0.01

TABLE 3

Mean Number of Correct Responses, Mean Validation Time, and Rank Order for Each Argument Type of CSR Set 2 Items by Mastery Level

Argument Type	Predicted Rank Order		Non-mastery (N = 61) Corrects	Rank Order	VT (Sec)	Rank Order	Mastery (N = 16) Corrects	Rank Order	VT (Sec)	Rank Order
[p, q]	1	Mean	7.07	1	1.28	3	9.44	1	1.49	2
		S.D.	(2.04)		(0.69)		(0.81)		(0.59)	
[p, Not-q]	1		5.38	2	1.22	3	9.56	1	1.37	2
			(2.45)		(0.87)		(0.63)		(0.61)	
[Not-p, q]	3		5.51	2	1.06	2	8.44	2	1.26	2
			(2.01)		(0.67)		(1.21)		(0.55)	
[Not-p, Not-q]	3		5.56	2	1.35	3	8.38	2	1.45	2
			(2.22)		(0.86)		(1.26)		(0.55)	
[q, p]	3		3.38	4	0.84	1	7.31	2	1.05	1
			(1.90)		(0.86)		(1.62)		(0.42)	
[q, Not-p]	3		5.28	2	2.08	4	7.63	2	1.44	2
			(2.27)		(1.16)		(1.45)		(0.66)	
[Not-q, p]	2		4.33	3	0.88	1	8.25	2	1.25	2
			(1.93)		(0.55)		(1.29)		(0.50)	
[Not-q, Not-p]	3		3.12	4	0.74	1	6.13	3	1.12	2
			(2.15)		(0.70)		(1.86)		(0.54)	

TABLE 4

Percent of Correct Responses for Each of Eight Conditional Syllogistic Arguments by Grade; Comparison with Previous Studies

Conditional Syllogistic Arguments	Current Study Grade			Taplin, Staudenmayer and Taddonio Grade				Taplin & Staudenmayer Grade
	5	7	College	5	7	8	11	College
[p,q]	60.4	76.8	88.5	90.0	81.0	89.2	94.3	99.1
[p,Not-q]	42.0	56.8	85.9	75.0	70.5	80.2	91.0	99.2
[Not-p,q]	49.6	60.8	72.2	24.0	28.5	30.8	46.3	88.4
[Not-p,Not-q]	62.0	52.0	69.2	10.3	19.3	26.0	37.9	18.0
[q,p]	38.8	31.6	54.1	7.5	13.2	34.6	51.5	16.2
[q,Not-p]	54.8	50.8	66.7	21.8	26.3	37.3	54.2	91.2
[Not-q,p]	37.2	47.2	68.5	66.6	63.8	69.8	66.9	90.3
[Not-q,Not-p]	22.8	38.4	50.0	58.7	54.6	61.4	59.3	86.8

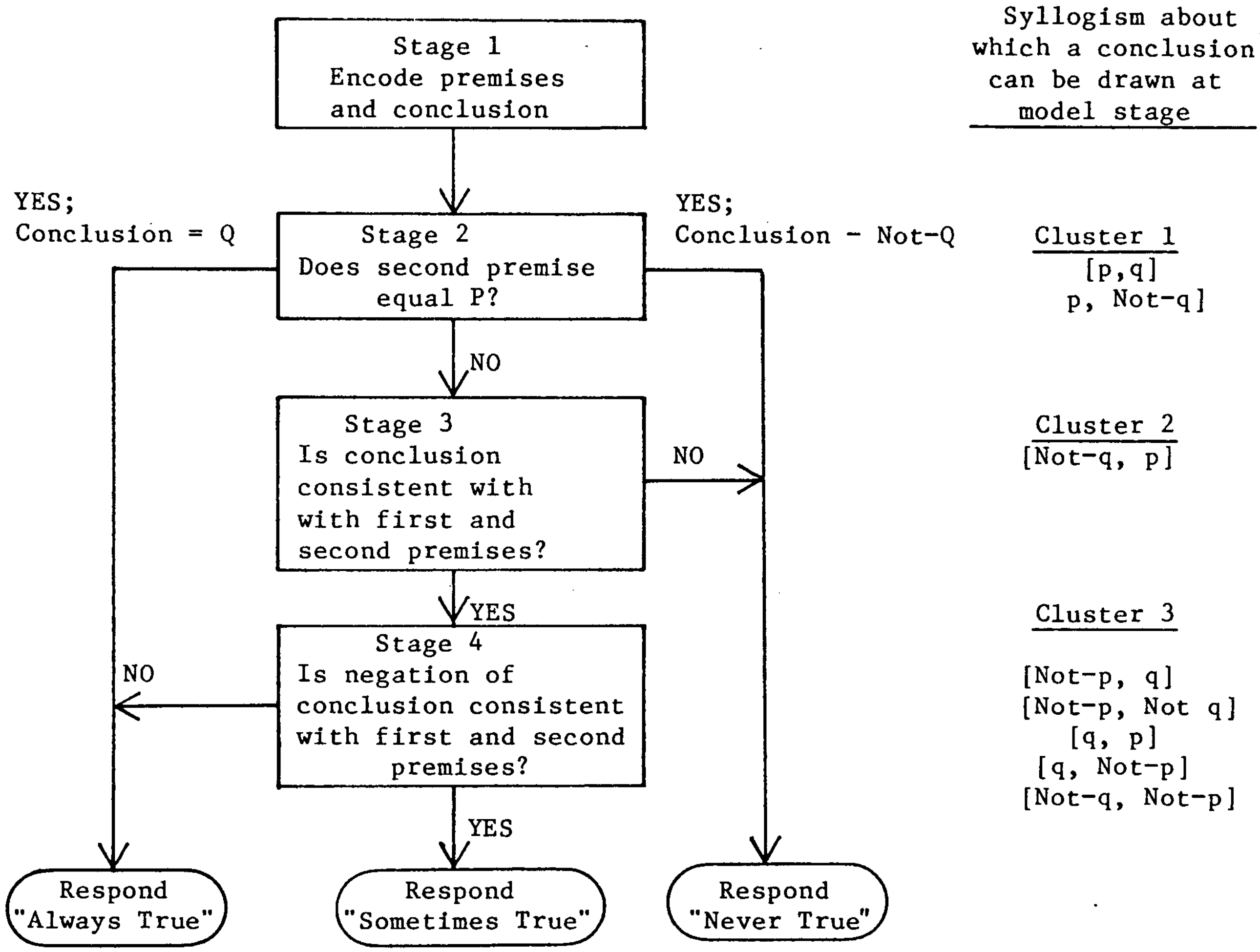

Figure 1. Marcus & Rips four-stage model for verification of conditional syllogisms; the point of which a conclusion can be correctly drawn for each syllogism is also shown.

APPENDIX A

EIGHT CONDITIONAL SYLLOGISTIC ARGUMENTS

ARGUMENT FORM	CONCLUSION	FIRST PREMISE	SECOND PREMISE	CONCLUSION	NOTATION	RESPONSE PATTERN CONDITIONAL	BICONDITIONAL
AFFIRMING THE ANTECEDENT	AFFIRMATIVE	If p, then q	p	q	[p, q]	Always true	Always true
	NEGATIVE	If p, then q	p	q	[p, Not-q]	Never true	Never true
DENYING THE ANTECEDENT	AFFIRMATIVE	If p, then q	p	q	[Not-p, q]	Sometimes true	Never true
	NEGATIVE	If p, then q	p	q	[Not-p, Not-q]	Sometimes true	Always true
AFFIRMING THE CONSEQUENT	AFFIRMATIVE	If p, then q	q	p	[q, p]	Sometimes true	Always true
	NEGATIVE	If p, then q	q	p	[q, Not-p]	Sometimes true	Never true
DENYING THE CONSEQUENT	AFFIRMATIVE	If p, then q	q	p	[Not-q, p]	Never true	Never true
	NEGATIVE	If p, then q	q	p	[Not-q, Not-p]	Always true	Always true

APPENDIX B

SELECTED SPANS FOR BACKWARD DIGIT SPAN TASK

n	Sequence
6	4,2,9,3,7,5,
5	9, 7, 4, 1, 6
3	3, 5, 2
8	8, 5, 3, 6, 4, 7, 9, 2
5	5, 2, 6, 8, 3
2	8, 5
9	5, 7, 4, 6, 1, 9, 3, 8, 2
3	8, 1, 4
6	8, 5, 7, 3, 9, 1
2	3, 7
7	7, 4, 2, 6, 8, 3, 5
9	9, 4, 8, 1, 6, 2, 6, 7, 3
7	9, 2, 4, 1, 5, 3, 8
4	3, 9, 4, 6
8	5, 9, 3, 7, 2, 6, 4, 8
4	2, 8, 1, 7

APPENDIX C

INITIAL INSTRUCTIONS TO SUBJECTS

Hello. My name is ____________________ and we're going to play two games on the computer in front of you using the numbered keys.

First, I would like you to type in your given names and press the RETURN key at the right of the keyboard.

(Subject types in christian names...)

Good! Now, enter your surnames and then, again, press the RETURN key.

(Subject types in surname ...)

OK. Now, the games you will be playing will require no more knowledge of the computer than that. You will each have two quite different tasks; one will be remembering a list of numbers and the other will be a true/false quiz. Some of you will have the numbers task first and others, the true/false. In both cases, you will have four practice problems first.

Let's start with the first task by pressing the spacebar.

APPENDIX D

INSTRUCTIONS FOR BACKWARD DIGIT SPAN TASK

The computer will show you a series of digits, or numbers, one at a time. At the end of each series, your job will be to try to remember all the digits and to list them back to the computer by using the appropriate number keys.

However, you are to list them in the reverse, or backwards, order to which they were shown. For example, you may see a series such as:

1 2 3 4

The computer will then show you these symbols '***' displayed in the middle of the screen. Your job will be list the digits back to the computer in the following order:

4 3 2 1

If you cannot remember one or more of the digits, you should enter a '-' in its place. Let's say that you forgot the digit, 3, you should then have entered the following:

4 - 2 1

The computer will give you time to remember each digit and will then go on to the next series. The word 'READY' will show just before a new series is about to start.

There are 4 practice and 16 actual items. You should work as quickly as you can but without making mistakes.

Now, let's try the first 4 practice items.

APPENDIX E

INSTRUCTIONS FOR THE CONDITIONAL SYLLOGISTIC REASONING TASK

This task will help your logical thinking ability improve, if you follow the instructions very carefully. Your job is to determine the correct conclusion that can be drawn from two premises (or clues). For example, here are two clues.

The first clue: If P, then Q.
The second clue: P

From these clues, you are to determine whether,

The conclusion: Q,
is 'always true (A),' 'sometimes true (S)' or 'never true (N).'

The important thing is to understand the meaning of each clue. To ensure your understanding, it is suggested that you read each clue carefully for up to 5 seconds and then think about what you have read for another 5 seconds.

Of course, if you finish reading and are sure of your answer, then you can immediately go to the next step by pressing the spacebar.

If you don't finish within 10 seconds, the computer will go on to the next step. The most important thing is to see whether or not your answer to each conclusion is correct. If your answer was incorrect, the corrected answer will flash on the screen and you should try to understand why that answer is right. Good luck.
