DOCUMENT RESUME

ED 099 415 TM 004 076

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| TITLE | Mental Processing Aspects of Two Formal Operational Tasks: A Developmental Investigation of a Quantitative Neo-Piagetian Model. |
| PUB DATE | [Apr 74] |
| NOTE | 11p.; Paper presented at the Annual Meeting of the American Educational Research Association (Chicago, Illinois, April 1974) |
| EDRS PRICE | MF-$0.75 HC-$1.50 PLUS POSTAGE |
| DESCRIPTORS | Adults; Children; *Cognitive Processes; *Complexity Level; Logical Thinking; Problem Solving; *Task Analysis; Task Performance |
| IDENTIFIERS | *Piagetian Theory |

ABSTRACT

Combinatorial and implicative operations were studied with tasks which eliminated many complexities found in Piagetian tasks, but which did not alter the logical strategies required by Piaget's task. Task difficulty in relation to information-processing demands of tasks and processing capacities of subjects at three age levels (8.0-10.1 and 10.2-12.1 years, plus adults) was investigated. The model used provided accurate predictions of task difficulty. Subjects who passed tasks reduced to rudimentary logical prerequisites subsequently failed logically equivalent tasks when quantitative constraints due to number of task variables or perceptual factors exceeded their processing capacities, and transferred operations to a Piagetian task. (Author)

# Mental Processing Aspects of Two Formal Operational Tasks: A Developmental Investigation of a Quantitative Neo-Piagetian Model

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Session 5.12/Piagetian Research II

PDR #18 (Palmer) 12:25 - 1:55

## Problem

Tasks used to identify different levels of cognitive functioning in Piagetian theory may be viewed, from a performance standpoint, simply as tasks of differing levels of difficulty. Piagetian theory may then be interpreted as asserting that the primary source of differential difficulty is the logical structure of the tasks. These tasks also differ, however, in information load and in potential sources of perceptual interference. Thus the Piagetian assertion that logical structure is the primary determinant of task difficulty is not convincingly confirmed merely by demonstrating that the tasks show the hypothesized order of difficulty.

In the present study new tasks were introduced so as systematically to vary sources of difficulty due to information processing demands and perceptual factors. The logical structure of the tasks was held constant. By administering these tasks to subjects of different levels of intellectual development it was possible to investigate the extent to which information processing demands and perceptual characteristics contributed to age differences in performance on logical tasks. Also, and with more direct bearing on Piagetian theory, it was possible to investigate whether, when other sources of task difficulty were reduced, children would still be unable to handle certain logical structures which Piagetian theory held to be beyond their level of competence.

Hypotheses were cast within a neo-Piagetian framework (Pascual-Leone, 1969, 1970; Pascual-Leone and Smith, 1969) which permits definite quantitative predictions about the information processing capacities of children at different ages. Pascual-Leone provides a method of analyzing task difficulty according to the number of subjectively independent schemes or chunks of information that must be integrated in a single mental operation. The number of schemes

that an individual can thus integrate (M-capacity) has been shown in a number of studies to be a direct function of age. moderated by situational components of tasks and by subjects' field dependence.

The specific hypotheses tested were as follows:

(1) Age differences in performance on logically equivalent tasks would depend on number of schemes to be integrated. Performance differences would not be shown on logically equivalent tasks when information processing demands did not exceed M-capacity.

(2) Task difficulty would be directly related to M-demands of tasks, not to amount of input and output information.

(3) Tasks with equivalent logical demands and equal numbers of variables but with salient vs. non-salient stimuli would be differentially difficult.

(4) Subjects (Ss) of all ages would generate efficient logical strategies when processing demands were reduced to the appropriate level.

(5) Experimental Ss below the stage of consolidated formal operations would have significantly higher scores than control Ss on a transfer test using Piagetian equipment.

While previous research has demonstrated the systematic nature of the development of M-capacity and its relevance to the development of logical thinking, this study is the first to explore the extent to which M-capacity may account for differences in logical problem-solving performance that have previously been attributed to stage of logical development and it is also the first to pit predictions based on the M-operator construct against those based on simple considerations of informational input and output.

## Experimental Methodology and Design

Tasks were designed for two logical operations characteristic of Piaget's formal stage (Inhelder and Piaget, 1958)--combinatorial logic (producing all

possible combinations of a set of variables) and separation of variables in controlled experimentation. Task analyses to determine the minimum number of schemes that needed to be integrated at any one point in a task indicated that for each task the number of schemes was equal to the number of variables involved.

For the experiment involving combinatorial logic Ss were presented with cards having from two to eight simple variable dimensions such as color and shape. Cards were designed in the form of overlays which could be used to produce all possible patterns of stimuli. Ss were presented with an initial task with numbers of variables set at their theoretical maximum capacity level (x) followed by tasks ranging from level x-4 to x+2. Tasks were controlled for input and output separately from M-space demands by varying the number of intra-variable dimensions. Chi-square analyses were used to compare the difficulty of tasks having the same numbers of variable dimensions but different numbers of possible combinations (e.g., 2x2x2x2 and 4x2x2x2) with tasks having different numbers of variable dimensions but equivalent numbers of possible combinations (e.g., 4x2x2x2 and 2x2x2x2x2).

For the separation of variables experiment cards similar to those in the preceding experiment were used. Different payoffs were associated with different variables and Ss had to test combinations of cards to determine effects of independent variables. Ss started with tasks at a low enough level that their M-capacity should allow them to develop an efficient strategy if they were logically capable of developing one and then were led through a graduated series of tasks with numbers of variables and perceptual factors systematically varied. Finally, Ss were tested on the Piagetian apparatus for testing variables associated with the flexibility of rods. Control Ss were given this task without going through the preceding task sequence.

An analysis of variance was used to determine experimental-control differences in ability to control variables.

The experimental materials duplicated or systematically eliminated all features of the Piagetian flexibility of rods task. The final card task was equivalent to the Piagetian task in logical structure, in number of variables, in number of possible controlled tests, in the relative discriminability or saliency of variables, in the number of variables that could be dissociated as against the number that were "bound together" in stimulus compounds, and even in the relative magnitudes of pay-offs or experimental outcomes.

The potential power of the methodology lay not only in the ability to modify task characteristics while holding logical structure constant but in the ability to specify quantitatively for each modification what its effect on information processing demands would be.

## Analysis of the Data

Within the age ranges 8-10, 10-12, and adults, Ss were selected who demonstrated the normal M-capacity, field independence, and low impulsivity. Total N=80--15 Ss at each of the lower age levels and 10 adults for each task sequence. Ten Ss at each age level receiving the combinatorial task sequence also served as controls in the separation of variables experiment.

Tasks were scored on the basis of actual number of combinations produced or number of variables controlled. Pass-fail criteria were established which, while permitting minor lapses of memory, allowed little chance for a subject to pass unless he used a logically adequate strategy. Results confirm all hypotheses:

1. Cumulative binomial probabilities were used to test the hypothesis that more than half of the Ss at each age level would pass combinatorial and non-salient separation of variables tasks set at x and fail those set at x+1.

The only deviation from predictions was that adults failed to pass combinatorial tasks at the expected level, performing less well than younger subjects. The hypothesis that performance differences based on logical demands would not be evidenced was supported by the fact that significantly more than half of these same Ss (except adults on the combinatorial task) developed appropriate strategies without instruction and succeeded on tasks up to and including those at their M-capacity level (see Tables 1 and 2).

2. McNemar's (1955) chi-square test for related observations on the same individual showed that M-demands (number of variable dimensions), not amount of input or number of combinations to be produced, was directly related to task difficulty.

3. Significantly more than half of the Ss at the two lower age levels (adults did not receive these measures) passed x+1 tasks with salient stimuli and failed x+1 tasks with less easily discriminable stimuli (see Table 3).

4. As predicted, significantly more than half of the Ss at each age level failed the initial combinatorial task and then (with the exception of adults) developed the appropriate strategy on tasks below their M-capacity level (see Table 4).

5. A 2-way ANOVA (age by experimental treatment) showed that experimental Ss at the two lower age levels controlled significantly more variables than control Ss on the Piagetian separation of variables apparatus (see Table 5 and Figure 1).

Experimental procedures were designed to provide data for further analyses of errors on particular variables across all control of variables tasks. These analyses supported hypotheses about the comparative effects of the saliency and dissociability of simulated and Piagetian variables.

## Evaluation and Discussion

In general, the approach of holding logical structure constant while varying other task characteris . within a neo-Piagetian quantitative framework has provided a powerful methodology for investigating the development of logical problem solving abilities. Hypotheses drawn from neo-Piagetian theory have been strikingly confirmed, while competing hypotheses that might be drawn from orthodox Piagetian theory or from a simplistic information-processing approach have not been confirmed. All ages showed the same logical strategies on tasks within their M-capacity limits and the same inability to develop strategies or to handle tasks when processing demands were beyond those limits. All ages showed the same effect of perceptual factors and the same tendency for performance to depend on number of variables rather than on number of stimulus combinations.

The one result contrary to predictions--the inferior performance of adults compared to children on the combinatorial tasks--does not contradict the theoretical interpretation of results. Two factors, overconcern with failure on the initial task and poorly assimilated mathematical strategies, appeared to create greater difficulties for adults than for children on these tasks.

The question naturally arises whether even younger children (say six-year-olds) would show the same logical strategies under appropriate conditions. This question is essentially unanswerable, in as much as the tasks cannot be further reduced in M-demand without losing their logical structure.

The most striking overall result is the similarity of performance of subjects at different ages, once adjustment is made for the differing information processing capacities of different age groups.

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TABLE 1

Confidence Limits and Number of Subjects Passing Combinatorial Tasks

| Age level of Ss | N | Tasks up to and at M-capacity Level | Tasks Exceeding M-capacity Level by One Unit | Confidence Limits for .059 Level of Significance (N=15) and .055 Level (N=10) |
|---|---|---|---|---|
| 8-10 | 15 | 13** | 2** | $X \leq 4$ and $X \geq 11$ |
| 10-12 | 15 | 11* | 2** | $X \leq 4$ and $X \geq 11$ |
| adults | 10 | 3 | 0*** | $X \leq 2$ and $X \geq 8$ |

Note.- X = number of subjects passing a task

* $p \leq .059$. (N=15)

** $p \leq .004$. (N=15)

*** $p \leq .001$. (N=10)

TABLE 2

Confidence Limits and Number of Subjects Passing Separation of Variables Tasks

| Age level of Ss | N | Tasks up to and at M-capacity Level | Tasks Exceeding M-capacity Level by One unit | Confidence Limits for .059 Level of Significance (N=15) and .055 Level (N=10) |
|---|---|---|---|---|
| 8-10 | 15 | 13*** | 0*** | $X \leq 4$ and $X \geq 11$ |
| 10-12 | 15 | 12** | 0*** | $X \leq 4$ and $X \geq 11$ |
| adults | 10 | 8*[a] | --- | $X \leq 2$ and $X \geq 8$ |

Note.- X = Number of subjects passing a task

[a]Task below M-capacity level, no higher level task presented.

*$p \leq .055$. (N=10)

**$p \leq .018$. (N=15)

***$p \leq .004$. (N=15)

TABLE 3

Confidence Limits and Number of Subjects Passing Salient and Non-Salient x+1 Separation of Variables Tasks

| Age Level of Ss | N | Salient x+1 Task | Non-Salient x+1 Task | Confidence Limits for .059 Level of Significance (N=15) |
|---|---|---|---|---|
| 8-10 | 15 | 12* | 0*** | $X \leq 4$ and $X \geq 11$ |
| 10-12 | 15 | 13*** | 0*** | $X \leq 4$ and $X \geq 11$ |

Note.- X = Number of subjects passing a task

**$p \leq .018$. (N=15)

***$p \leq .004$. (N=15)

TABLE 4

Confidence Limits and Number of Subjects Passing Initial Combinatorial Task and Subsequent Tasks up to and at M-Capacity Level

| Age Level of Ss | N | Initial Task (at M-capacity Level) | Tasks up to and at M-capacity Level | Confidence Limits for .059 Level of Significance (N=15) and .055 Level (N=10) |
|---|---|---|---|---|
| 8-10 | 15 | 1** | 13** | $X \leq 4$ and $X \geq 11$ |
| 10-12 | 15 | 0** | 11* | $X \leq 4$ and $X \geq 11$ |
| adults | 10 | 0*** | 3 | $X \leq 2$ and $X \geq 8$ |

Note.- X = Number of subjects passing a task

* $p \leq .059$. (N=15)

** $p \leq .004$. (N=15)

*** $p \leq .001$. (N=10)

TABLE 5

Analysis of Variance: Age by Experimental Condition for Piagetian Separation of Variables Task

| Source | SS | df | MS | F |
|---|---|---|---|---|
| Age (A) | 7.2275 | 2 | 3.6137 | 26.9257*** |
| Experimental Condition (B) | 16.6821 | 1 | 16.6821 | 124.2963*** |
| A X B | 6.5695 | 2 | 3.2847 | 24.4745*** |
| Error | 8.5896 | 64 | 0.1342 | |

***$p < .001$.

FIGURE 1

Piagetian Separation of Variables Task: Interaction of Age with Experimental Condition