DOCUMENT RESUME

ED 194 532 TM 800 656

AUTHOR Holzman, Thomas G.: And Others
TITLE Cognitive Determinants of Analogical Reasoning on Intelligence Tests.
PUB DATE Mar 80
NOTE 16p.: Paper presented at the Annual Meeting of the Southeastern Psychological Association (Washington, DC, March 26-29, 1980).

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Age Differences: Arithmetic: *Cognitive Processes: College Students: Grade 4: Grade 5: Higher Education: *Induction: *Intellectual Development: Intelligence Differences: Intelligence Quotient: Intelligence Tests: Intermediate Grades: Number Concepts: Reaction Time: Standardized Tests

ABSTRACT

The cognitive determinants of number analogy performance were studied by systematically manipulating the processing demands imposed by the items. To explore sources of developmental differences in analogical reasoning, subjects were included from two age levels, grades 4 and 5 and college. To allow the investigation of individual differences in reasoning ability, the children were selected to represent two general aptitude levels, average IQ and high IQ. The experimental number analogies correlated highly with the number analogies portion of a standardized intelligence test: the Analysis of Learning Potential. In each group a combination of domain-specific and general procedural knowledge factors accounted for more than 70% of the variance in item solution difficulty. The most critical processing demand affecting successful performance was the amount of solution-related information to be assembled and managed in working memory. Domain-specific and general procedural knowledge factors differentiated adults from children, while only specific, factual knowledge competencies seemed to differentiate between IQ levels in children. (Author/CP)

Cognitive Determinants of Analogical Reasoning on Intelligence Tests

Thomas G. Holzman

Georgia State University

Robert Glaser

University of Pittsburgh

James W. Pellegrino

University of California, Santa Barbara

Paper presented at the meetings of

the Southeastern Psychological Association

Washington, D. C.

March, 1980

Running head: Cognitive Determinants

Cognitive Determinants of Analogical Reasoning on Intelligence Tests

The present study is an attempt to learn about the cognitive components of performance on standardized intelligence tests. The focus of this investigation is on number analogies, because they exemplify a prominent class of aptitude tests, rule induction problems. Rule induction is of special concern because factor analytic studies have frequently identified it as an important factor emerging from the aptitude test performances of both adults and children (Thurstone and Thurstone, 1941; French, 1951; Adkins and Lyerly, 1952; Guilford, 1967; Cattell, 1971; Ekstrom, 1973). The regular occurrence of this factor in many test batteries suggests a close relationship between inductive reasoning and school success, making this an especially important competency for educators to learn about. Furthermore, an investigation of inductive reasoning may yield some information about the psychological components of other intelligence factors as well, since Thurstone and Thurstone have asserted that rule induction, as a second order factor, may actually be Spearman's *g*.

Objectives

Three sets of issues will be examined in this presentation. First, an attempt will be made to identify some of the major solution requirements imposed by different types of number analogies and to assess the influence of those requirements on rates of solution. Second, information is sought about the nature of intellectual development. This will be obtained by comparing the performances of subjects of different ages on distinct types of analogies to determine whether certain processing demands exert greater influences at one age level than another. Finally, an effort will be made to identify the types of solution requirements that are most responsible for the individual differences in performance that accompany psychometrically devised intelligence tests. This will be accomplished by identifying specific solution requirements that discriminate between subjects of distinct mental ages within a given chronological age group.

Method

Materials

Since standardized tests often confound changes made along two or more problem dimensions, and since there are usually only a few instances of any particular task characteristic, it is often difficult, if not impossible, to determine the independent contribution of each identifiable processing demand to test performance. To circumvent these limitations, 44 number analogies were especially developed for this experiment. These analogies incorporated and manipulated the same features that a preliminary study had shown to be characteristic of standardized tests. However, the experimentally devised problem set was more systematic in its manipulation of task characteristics and contained more instances of those characteristics for greater reliability in revealing sources of solution difficulty.

As illustrated in Table 1, the experimental number analogies consisted of two complete pairs of terms and a third pair that the subject had to complete. The problems differed from each other according to the number of arithmetic operations that were applied to one member of a pair to generate the other member, according to the qualitative categories of these operations (e.g., addition, subtraction, multiplication, etc.), according to the magnitudes of these operations (e.g., +1 versus +12), and according to their ambiguity in suggesting a solution rule.

Subjects

To permit the exploration of sources of developmental differences, the experimental number analogies were administered to subjects at two different age levels, fourth and fifth grade children and adult college students. To allow further insights into the nature of individual differences in intelligence, the fourth and fifth grade subjects were selected into two distinct groups on the basis of previously obtained IQ scores, an average intelligence group, with IQ's ranging from 86 to 103, and a high intelligence group, with IQ's ranging from 130 to 158. Altogether then, differences in age and general intelligence were represented by three groups, and 18 subjects were assigned to each of them.

Procedure

Before attempting the experimentally devised number analogies, all subjects were administered all grade levels of the number analogies portion of the Analysis of Learning Potential (ALP). This instrument was presented in a group setting, using the standard paper-and-pencil format and time limitations prescribed in the test manual. The ALP analogies provided an opportunity for a subsequent check on whether the experimentally devised items were assessing the same competencies as the standardized test items that they were purportedly modeled after. If the total scores on the experimental instrument positively correlate with those on its standardized counterpart, this would support the relevance of the experimental test results to the standardized tests that are the ultimate focal point of this research.

Several days after the administration of the ALP, subjects were individually tested on the experimental analogies. One item was presented at a time on the screen of a CRT computer terminal, and the subject was allocated up to 75 seconds to type one number into the computer to complete the pair.

Results

All subjects completed the ALP number analogies and the experimentally devised problems. The correlations between the scores on these two instruments indicated that the experimental test was achieving its purpose in systematically assessing competencies underlying standardized test performances. For the average IQ children, high IQ children, and adults, respectively, the Pearson correlations between total scores on the two instruments were .71 ($p < .001$), .76 ($p < .001$), and .58 ($p < .05$).

To determine the processing demands that most affected performance on the analogies, a series of multiple regression analyses were employed. Solution probabilities for individual analogies in the experimental set constituted the dependent variable, and the experimentally manipulated task characteristics were the predictor variables. These analyses indicated that two general classes of solution requirements determined the difficulty of the problems. These can be referred to as domain-specific knowledge demands and general procedural knowledge demands. For number analogies, the needed domain-specific knowledge entails an understanding of the sequential nature of numbers, as well as skill in recognizing and executing specific arithmetic operations (e.g., addition by two, division by three, etc.). On the other hand, the general procedural knowledge involves the coordination of solution-related information in working memory while assembling and verifying a solution rule for the analogy.

Working Memory Demand

Of the different predictors included in the regression analyses, the most influential one for all three groups of subjects was a general procedural knowledge requirement, the working memory load imposed by an item. Number analogies vary in the number of arithmetic operations that their solution rules incorporate, and the more operations that must be assembled and kept track of, the more mental work space is required. For example, Item 1 of Table 1 makes a minimal demand on working memory because the examinee has no numerical transformations to remember in completing the third pair. The answer is really in external memory. It's the same number that occurs in the first position of the third pair. On the other hand, Item 2 makes slightly greater demands on working memory. There, the examinee must notice the existence of a +3 relation between the members of each pair, mentally apply that operation to the first term of the third pair, and then hold the result of that operation in working memory long enough to fill in the blank. Item 6 imposes still greater memory demands. To solve that analogy, the examinee must notice, retain, and execute two distinct operations which are applied in sequence, x2 and +1. Apparently, these increases in solution-related information quickly overload the limited mental work space that most people possess and constitute the most critical determinant of item difficulty for this type of task.

To investigate sources of developmental and individual differences in analogical reasoning, a two-way analysis of variance was applied to the data. Item features and subject characteristics were the independent variables, and solution rates for individual items again constituted the dependent variable.

As expected, adults performed successfully on significantly more problems than children did (80% versus 52.5%, $p < .001$), and high IQ children solved significantly more problems than average IQ children (58% versus 47%, $p < .05$). Moreover, the age of the subjects interacted with the memory demands of the analogies ($p < .001$). As can be seen in Figure 1, a major decline in the children's performances began as soon as any increases occurred in information coordination demands beyond the repetition of a single integer. The adults, on the other hand, performed with almost the same accuracy for the first two information coordination levels, but were seriously impaired at the third, and most demanding, level. This pattern of interaction effects is consistent with research by Pascual-Leone (1970) and Case (1972, 1978) suggesting that the effective capacity of a person's information management space, or working memory, increases developmentally. Evidently, the adults in this study had evolved more storage space or better strategies for using that space which enabled them to effectively manage more rule-related information than their younger counterparts. However, even those expanded capabilities eventually become inadequate as the highest memory level problems were encountered.

Domain-Specific Knowledge Demands

Besides the role played by working memory in determining analogy performance, the multiple regressions and analysis of variance implicated relational ambiguity as a critical influence on solution. In some problems, like Item 2 of Table 1, an examination of the first pair immediately suggests one relation that can be employed to correctly complete the problem, addition by three in this case. Sometimes, however, there are competing or misleading relations which can be eliminated only by testing their applicability to the second pair as well as the first. For example, an initial glance at the first pair of Item 3 might suggest the employment of a x2 relation rather than the +2 that is actually required. Likewise, an examinee would probably hypothesize +4 as the relation governing Item 6 until it was checked for applicability to the second pair. Ambiguity is thus a domain-specific variable, since it results from different levels of familiarity with distinct types of arithmetic operations. However, it also involves elements of general procedural knowledge, since the misdirections caused by ambiguity can be overcome by a verification strategy that checks for consistent occurrences of a relation across all pairs of the analogy.

All three groups of subjects had difficulty solving items with ambiguous first pair relations. In fact, when this variable was employed with working memory demand as the sole predictors of performance, the resulting regression equations accounted for most of the solution variance among the 44 analogy items for all three groups of subjects: 87% for the average IQ children, 86% for the high IQ children, and 74% for the adults (all p's $< .001$).

Other processing demands specifically tied to the numerical content domain also contributed to subjects' performances on the number analogies. One of these was the magnitude of the arithmetic operation required to generate the second member of the pair from the first. When single transformation analogies were divided into two groups on the basis of the relative magnitudes of the arithmetic operations they employed (e.g., Item 2 versus Item 4 in Table 1), comparisons of the two sets indicated that the high magnitude analogies were considerably more difficult than their low magnitude counterparts ($p < .001$). Furthermore, as illustrated in Figure 2, magnitude interacted with the age of the subjects ($p < .01$). Both adults and children were impaired by high magnitude operations, but these effects were clearly more serious for the children.

In addition to magnitude, the qualitative category of arithmetic operations affected subjects' performances. As shown in Figure 3, this task dimension interacted with both the age level ($p < .001$) and the intelligence level ($p < .05$) of the subjects. The adults did quite well on all types of number analogies, but they solved items involving multiplication and division with somewhat greater accuracy than those involving addition and subtraction. Similarly, the high IQ children did slightly better with multiplication and division than with addition and subtraction. However, the average IQ children solved more subtraction analogies than division analogies, while performing equivalently on addition and multiplication. Apparently, the adults, and to some extent the high IQ children, had a good command of both the multiplication and division tables. This enabled them to readily detect and accurately apply multiplication and division operations when they came up in the analogies. On the other hand, while the average IQ fourth and fifth grade children had acquired skill in multiplication that matched their high IQ counterparts, they still had not developed proficiency with tabled division operations. This inadequacy in domain-specific knowledge appears to be directly responsible for the inferior performance of these children on a number of test items. Furthermore, Figure 3 suggests that the average IQ children were affected by the direction of the operations in the analogies. Both incrementing operations (addition and multiplication) were clearly easier for them than either decrementing operation (subtraction and division). No such effect was apparent for the high IQ children or the adults.

Discussion

Together, the analyses presented here indicate that analogical reasoning, and probably other intelligence test performances as well, can be explained in terms of an interactive system of cognitive processes. Low test scores may be due to inadequacies in general solution procedures, including poor management of information in working memory and failures to fully test the appropriateness of hypothesized solution rules. However, it is quite notable that failures on tests of abstract reasoning sometimes result from inadequate knowledge of facts and skills directly taught and practiced in school. The superior scores of the adults in this study resulted from greater proficiencies with both of these classes of solution skills. On the other hand, domain-specific knowledge alone was the major source of solution discrepancies between children of different general intelligence levels. The challenge for future research is to better specify the mechanisms associated with the activation and growth of these different solution determinants and to use this kind of analysis to augment the diagnostic power of standardized tests already valued for their predictive capabilities.

References

Adkins, D. C., and Lyerly, S. B. Factor analysis of reading tests. Chapel Hill, N.C.: University of North Carolina, 1952.

Case, R. Learning and development: A neo-Piagetian interpretation. Human Development, 1972, 15, 339-358.

Case R. Intellectual development from birth to adulthood: A neo-Piagetian interpretation. In R. S. Siegler (Ed.), Children's thinking: What develops? Hillsdale, N.J.: Lawrence Erlbaum Associates, 1978.

Cattell, R. B. Abilities: Their structure, growth and action. Boston: Houghton Mifflin, 1971.

Ekstrom, R. B. Cognitive factors: Some recent literature. Tech. Report No. 2, Princeton, N.J.: Educational Testing Service, July, 1973.

French, J. W. The description of aptitude and achievement tests in terms of rotated factors. Psychometric Monographs, No. 8, 1951.

Guilford, J. P. The nature of human intelligence. New York: McGraw-Hill, 1967.

Pascual-Leone, J. A mathematical model for the transition rule in Piaget's developmental stages. Acta Psychologica, 1970, 32, 301-345.

Thurstone, L. L., Thurstone, T. G. Factorial studies of intelligence. Chicago: University of Chicago Press, 1941.

Table 1

Some Different Types of Number Analogies

1) No Numerical Transformations (Identity Relation)

2:2 7:7 23:_____

2) One Low Magnitude, Unambiguous Addition Operation (+3)

25:28 4:7 65:_____

3) One Low Magnitude, Ambiguous Addition Operation (+1)

2:4 7:9 3:_____

4) One High Magnitude, Unambiguous Addition Operation (+12)

5:17 19:31 30:_____

5) One High Magnitude, Ambiguous Subtraction Operation (-12)

24:12 22:10 38:_____

6) Ambiguous, Two-Operation Relation (x2, +1)

3:7 11:23 10:_____

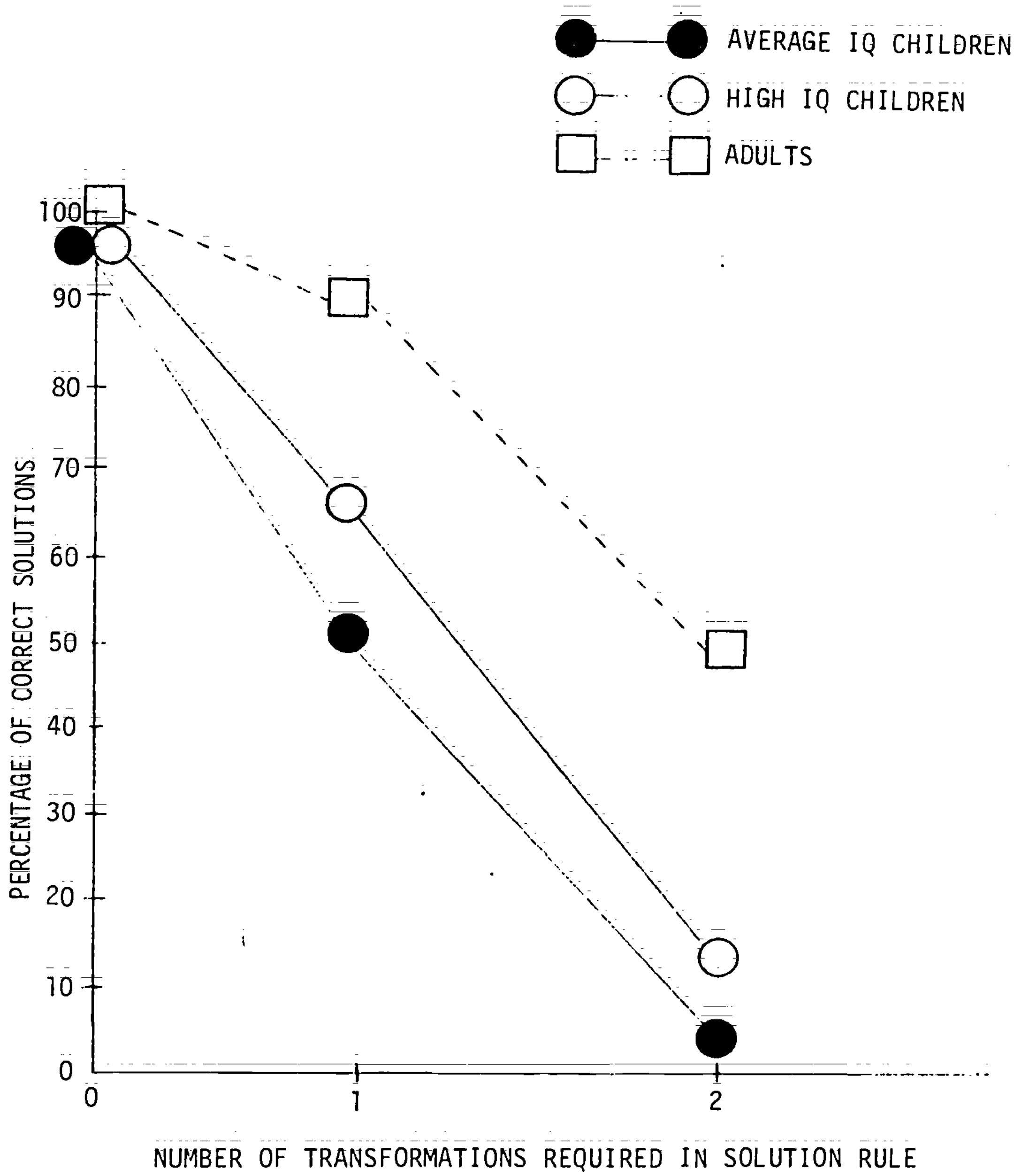

Figure 1. Percentages of correct solutions for number analogies requiring different numbers of transformations.

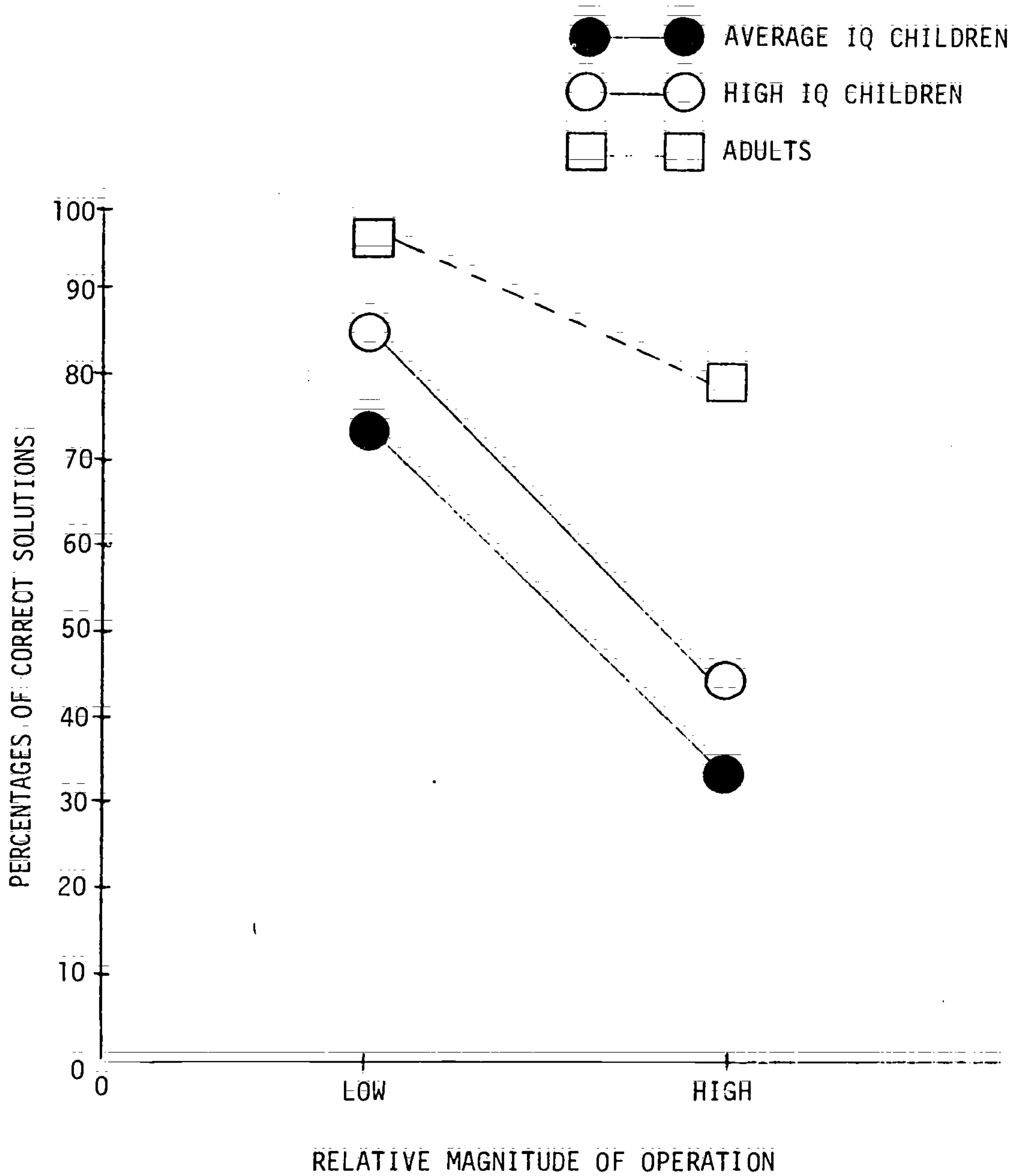

Figure 2. Percentages of correct solutions for number analogies requiring different magnitudes of arithmetic operations.

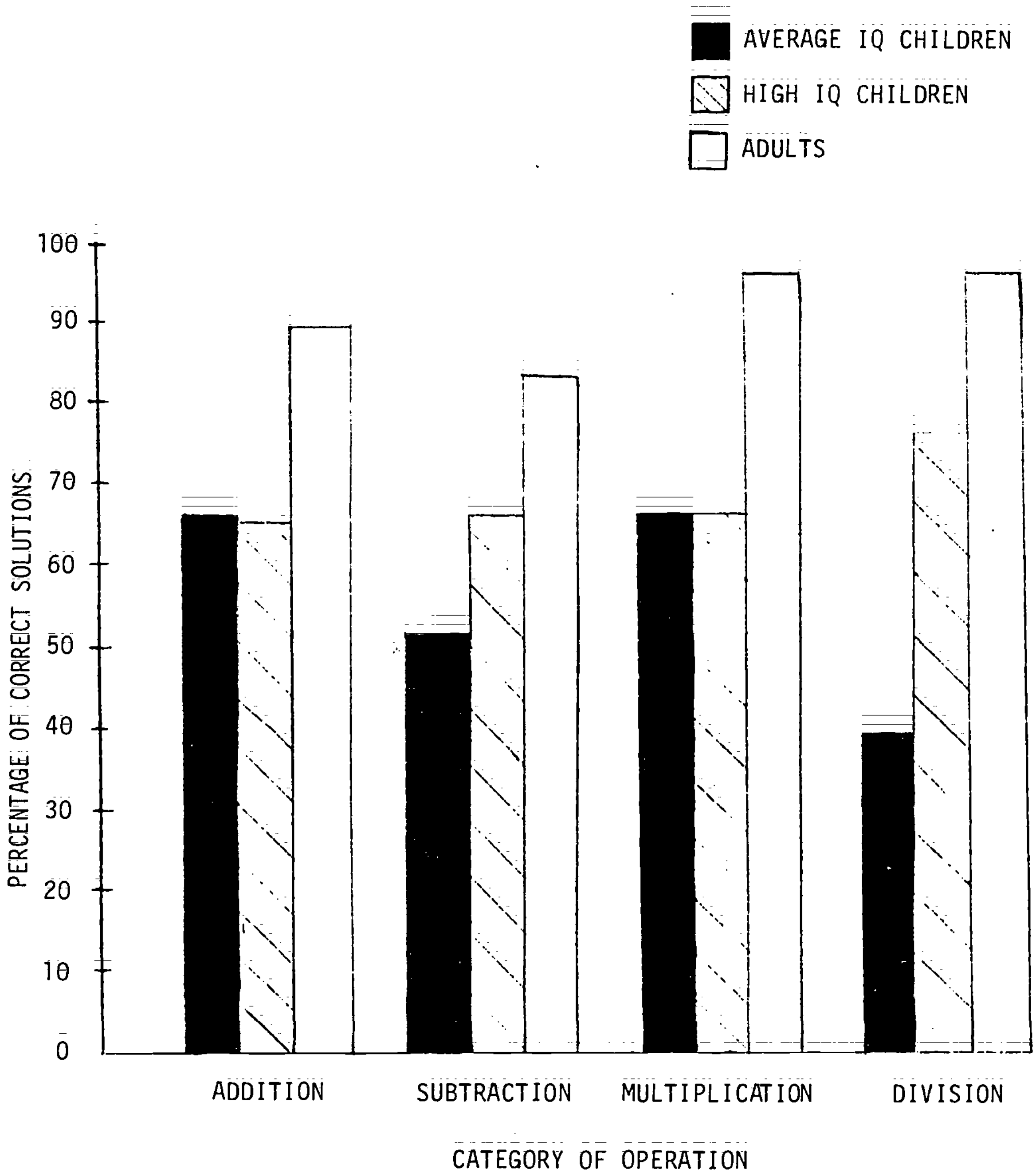

Figure 3. Percentages of correct solutions for number analogies requiring different qualitative categories of operations.