A comparison of operational seriation of lengths and weights in Piagetian tasks

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A COMPARISON OF OPERATIONAL SERIATION OF LENGTHS AND WEIGHTS IN PIAGETIAN TASKS

by

Marian Peglar

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1969
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>METHOD</td>
<td>26</td>
</tr>
<tr>
<td>RESULTS</td>
<td>37</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>54</td>
</tr>
<tr>
<td>CONCLUSION</td>
<td>74</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>76</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>78</td>
</tr>
<tr>
<td>APPENDIX A</td>
<td>79</td>
</tr>
<tr>
<td>APPENDIX B</td>
<td>80</td>
</tr>
</tbody>
</table>
INTRODUCTION

Psychologists interested in cognition have been divided into two groups: (1) the neobehaviorists, who maintain a basically S-R orientation and conceptualize thinking in terms of chains of S-R links, while allowing the possibility of meditational processes; and (2) the cognitive psychologists, who pay considerably more attention to conscious experience and the complex mental organization involved in thinking (Ausubel, 1966).

The position of Jean Piaget relative to this dichotomy remains unclear since he shares common concerns with both groups but also has substantive points of disagreement with each of the standard positions. The present research was conducted in the Piagetian theoretical tradition (with added emphasis on statistical treatment of data and greater attempts to describe fully the actual manipulations used) and could conceivably be conceptualized within either basic framework since the data collected were observable sequences of behavior. However, the inferences drawn concerning the plans and strategies which the Ss seemed to be utilizing may suggest an outlook more sympathetic to the cognitive psychologists, leaning toward the approach of Bruner, Olver, and Greenfield (1966) or the "subjective behaviorism" of Miller, Galanter, and Pribram (1960).
The particular cognitive concept to be studied in the present research is that of seriation, the ability to order objects or verbal stimuli in an ascending or descending series according to some attribute in which the elements of the series differ.

Psychologists have traditionally studied the child's behavior in seriating elements as a manifestation of general problem-solving or intellectual ability. Early investigators of seriation were Binet and Simon (1929) who used a weight seriation task in which children arranged five boxes of different weights in order from the heaviest to the lightest as an item in one of their first tests of mental development. The early, sporadic concern with seriation typified by this study is not a fundamental concern to the present study. The only systematic research on seriation has been done by Piaget and his co-workers and will be discussed below in detail together with some pertinent theoretical considerations.

As opposed to seriation, however, there have been many investigations devoted to transitivity, a concept closely related to seriation. A logically transitive relation has properties which allow one to conclude that a certain relationship exists, having been given that two other relationships hold; e.g., because "greater than" is a transitive relation one can conclude from "\(a\) is greater than \(b\)" and "\(b\) is greater than \(c\)" that "\(a\) is greater than \(c\)". Piaget (1968a) has expressed the psychological relationship between transitivity and seriation
as follows: "at the stage of concrete operations (7 to 10 years) ... we get operative seriations with order in two senses from which comes transitivity, until then ignored or stated without necessity (p. 56)." Since studies of transitivity have relevance to seriation both in terms of experimental techniques used and relatedness of logical structure, they will be discussed briefly before seriation itself is considered.

Transitivity Studies

The work on transitivity can be classified under two major headings: (1) investigation of problems for eventual use in mental tests, and (2) theoretically oriented research, usually based on Piagetian considerations, either to confirm, extend, or challenge reported findings. Both of these areas of interest have recently shown similarities in the growing concern of investigators with the processes involved in problem solution rather than the simple truth or falsity of solution. This trend, reflecting Piaget's influence, is exemplified in the mental testing field by the increasing emphasis on process in transitivity studies as reflected by Burt (1919), Hunter (1957) and Donaldson (1964), all operating within the British tradition and interested mainly in solution of verbal problems. Each study shows a significant increase over the preceding one in attention paid to the mental process involved in problem solution.
Transitivity has also been studied from a developmental-cognitive view which has been directly influenced by the Geneva school. This work has attempted to ascertain age of attainment of the transitivity concept in relation to conservation as well as to explore methods of teaching transitivity concepts (Smedslund, 1963a, b; Braine, 1964). Stimuli used have often been physical objects rather than verbal items. Disagreements over the average age of attainment of logical operations has led to agreement on the necessity for specifying carefully the experimental context in which the operations are performed (Smedslund, 1966), even to the point of a highly detailed analysis of the comparative difficulty of various formal types of transitivity and strategies employed in the solution of repeated problems (Smedslund, 1968). The present work shares with current developmental transitivity studies an interest in the mental processes actually used by subjects in problem-solving, with specification of the context of the task for the purpose of evaluating the impact of this context on the logical operation to be performed (i.e., seriation).

Seriation

Inhelder and Piaget (1964) have contrasted their own theoretically oriented process-centered research in areas of logical thought with some of the older, more pragmatically oriented approaches. The Geneva school views seriation as an operation which is attained at the stage of concrete operations
(aged 7-10) contemporaneously with other operations showing similar structure. Piaget and his co-workers have used seriation tasks in studying several different aspects of cognitive growth and hence their approach to seriation has varied, depending on the goals of the research involved. In the study of the development of numeration (Piaget, 1952), the child's ability to construct number concepts was assumed to derive from his experiences with discrete objects which he could (1) join together in classes, concentrating on their equivalences, or (2) seriate according to their differences. From this point of view construction of number is seen as resulting from the synthesis of the two requisite abilities discussed above. Hence, seriation tasks were studied in close conjunction with classification and numeration tasks.

The problem of studying how children learn to quantify continuous qualities (substance, weight, or volume) which seem initially to be indissociable from the objects manifesting them also involves seriation but in a different context from the above, this time deriving from continuous rather than discontinuous entities (Piaget and Inhelder, 1962). Here it was assumed that representation of the world involves (among other compositions) the ability to deal with objects differing in some quality (e.g., weight). Ordering or seriating the objects was considered an ability requisite to quantifying the attribute. Hence, seriation of weights was studied in detail in this research.
The reporting of findings in the two above-mentioned publications has been criticized for its lack of attention to many important variables such as subjects used, exact procedures, and statistical handling of the data. Elkind has repeated many of the studies and reported his results in more satisfactory detail. His replications (1964) have included some of the work with seriation reported by Piaget (1952). A later book by Inhelder and Piaget (1964) studied seriation again in a slightly different context, this time with greater attention to reporting information concerning numbers of subjects and procedures used. In these studies seriation and classificatory behaviors were investigated in order to emphasize their concurrent but independent development and their relative freedom from basic cognitive dependence on perceptual activity. Seriation was found to be especially useful in studying anticipation (foreseeing the results of actions that have not yet been performed) which, together with hindsight (reviewing past actions from the vantage point of present activity), is indispensable to reversibility in thinking, one of Piaget's basic concepts. The Genevans have also found seriation to be a useful vehicle for studying memory processes. Inhelder (1969) has recently reported some of this work.

The present study investigated operational seriation within the framework of Piaget's developmental theory with special attention to the strategy used by the subject in carrying out the actual seriation.
This theory is notoriously difficult to understand and elucidate both because of the number and length of relevant publications and the breadth and complexity of the issues involved. Piaget's multifarious interests include genetic epistemology, experimental psychology, perception, cognition, logic, and structuralism. Piaget has published extensively and profoundly in all of these areas throughout a long and distinguished career. Flavell (1963) has been the most thorough expositor in English of Piaget's work. He has discussed the difficulties involved in presenting a comprehensive summary of Piaget's output. In contrast to Flavell's global view the present work is concerned with one very limited aspect of Piaget's theory (i.e., seriation) and is designed to investigate in detail only a restricted range in the course of development of this operation. Despite the narrowness of focus it is necessary to present some brief preliminary comments on Piagetian theory in order to make comprehensible the nature of the research. No attempt will be made to survey the whole theory, but rather the concepts relevant to the development of seriation ability will be discussed in theoretical perspective.

Innate and Early Functioning

Piaget (1968b) has taken the position that there is innate neurological and organic functioning but no structured hereditary programmation. Thus the infant is equipped at
birth with a repertory of behaviors which are the points of departure for the development of intellectual functioning. These behaviors are general co-ordinations of actions, and no distinction is drawn between reflexes and spontaneous movements.

In these behaviors one finds both functional factors and mechanisms that can be used to build structures. The functional factors are assimilation, in which objects in the environment are incorporated into mental structures; and accommodation, in which structures are modified by environmental situations. The structural mechanisms are relations of order, hierarchies and correspondences. It might be noted that ordering, the basis of seriation, is considered to be one of the most primitive processes. In the course of development the co-ordinations of behaviors become progressively more complex and concomitantly their internal representations become more intricate but always tending toward structural organization. There is a pervasive regulatory process which tends to maintain the intellectual equilibrium of the organism in relationship to its environment. This force is known as equilibration.

Pre-Logical Cognition

Piaget's theory, is a stage theory of development. There are four basic stages: (1) sensorimotor (birth to two years), (2) preoperational (two to seven years), (3) concrete operations (seven to eleven years), and (4) formal operations
(eleven and older). The criterion for having reached a given stage is the attainment of cognitive processes which show the logical structure characteristic of that stage. The ages associated with stages are based on averages and atypical age levels are not unexpected. However, the order of stage development is invariant for a given individual, and conforms to the sequence given above.

In the sensorimotor period the child's mental organization is characterized by schemes or, loosely, sensorimotor concepts. These internalized patterns of behavior tend toward equilibrium states without, however, achieving truly reversible regulation. During this period occur activities which are the precursors of operational seriation. For example, the child becomes able to build towers of nested blocks (Inhelder and Piaget, 1964). The child engaged in this type of rudimentary seriation uses no systematic co-ordination of the "less than" and "greater than" relations. That is, he has no conception of the possibility of an object's being both greater than some objects and less than other objects. The child's absolutist approach leads to the tendency to see an object as either "big" or "little." The tower building activity is based on much trial and error and practice with specific relations obtaining between the particular objects to be manipulated. As the child in the preoperational stage approaches attainment of operational seriation his thinking passes through several phases which Piaget has described in
detail in several books previously discussed (Piaget, 1952; Piaget and Inhelder, 1962; Inhelder and Piaget, 1964.) In these cross-sectional studies Piaget applied his usual clinical methods of questioning to children in the age range of four to ten. From this research he concluded that there are two discriminably different types of seriation behavior before the operational stage.

During the first stage, the child aged about four or five shows an absence of the ability to co-ordinate serial relations or even to anticipate the form of the final result. He may not even inspect all the elements to be seriated before he begins the seriation. In the second stage the six to eight year old begins to be able to anticipate the goal and to achieve a seriation with considerable use of trial and error and the setting up of several preliminary shorter series. At the next stage the nine year old child has finally achieved operational seriation, at which time he can anticipate the exact form of the result and can use the most efficient strategy to attain his goal. This optimum strategy will be discussed later in greater detail.

Concrete Operational Cognition and Groupings

As opposed to sensorimotor intelligence, operational thinking is much more logical and in a higher state of equilibrium. Operations are defined to be internalized, reversible actions. Reversibility, in turn, is the property of being able to be
canceled by an inverse transformation. Operations are bound up with other operations into integrated systems called structures. At the stage of concrete operations the child's thought can, for the first time, be represented by a truly logical structure, the grouping. Structures are not directly observable and hence their presence must be inferred from behaviors which are judged to be hallmarks of certain kinds of thinking. In the case of concrete operations the child shows the ability to deal logically with classes and relations. He is not aware of the logical implications of his behavior nor is he yet able to deal with abstract logical propositions since he still can structure only immediately present reality.

The grouping, the characteristic structure of the concrete operational stage, has been discussed in detail by Piaget (1957) and Flavell (1963). Briefly, it can be thought of as an algebraic system consisting of a set of elements and an operation. The system is associative, has closure and reversibility and contains a general identity element. The above properties are the characteristics of a mathematical group. In addition to the group properties the grouping also has the property of containing special elements which can act as identity elements for certain other elements, but not for all elements.

Reversibility of thought is essential to concrete operational thinking. In seriating, reversibility is exemplified by the child's increased ability to use and
co-ordinate anticipation and hindsight or, in other words, to master a kind of intellectual shuttling process. The two major types of grouping concern (1) classes and (2) relations, each showing a different type of reversibility; the former utilizing negation and the latter reciprocity. The particular grouping which represents concrete operational seriation is that of the addition of asymmetrical relations; hence its reversibility shows the characteristics of reciprocity.

Formal Operational Cognition and Groups

The child of 11 or 12 is developing the cognitive capacity to think logically and systematically about events which need not be physically present; that is, he can generate hypotheses concerning abstract relationships. His thinking exhibits the structural characteristics of mathematical groups mentioned previously. In particular he has mastered what Piaget has called the INRC group in which, for the first time, he can combine the two types of reversible thinking (negation and reciprocity) into one structure. Although Piaget has not followed logical seriation through this period of the beginnings of formal operations, the present research investigated performance in a seriation task which required thinking at this more abstract, hypothetical level.
Importance of Structures

Logico-mathematical structures like the groups mentioned above are of central importance to Piaget's theory. He defines structures as systems of self-regulating transformations (Piaget, 1968a). Structures must be amenable to formalization; in Piaget's theory they are expressed as logical models which represent operational thinking. Piaget has admitted that his belief in structures is so strong that he runs the risk of being accused of a priorism - in this case in the form of assuming in advance that there do exist abstract structures capable of serving as models for mental processes. However, he is emphatic in stating that empirical research alone determined the form of these models and he had no fixed preconceptions of how the structures might be organized.

Piaget's broader goals, beyond the usual bounds of experimental psychology, include obtaining an understanding of (1) how man develops the power to think logically, and (2) the relationship which exists between logical mathematical structures and the organicist structures of the brain (Piaget, 1968a). Thus structuralism and the possible use of common abstract logical models in different areas of research hold, for Piaget, a possible key to the solution of the mind-body problem. The hope of the eventual discovery of the mechanisms of an isomorphism between states of consciousness and physical causality explains Piaget's insistence on the importance of the structures. Whether or not one is sympathetic with Piaget's
belief in the explanatory value of abstract logical models in psychology - Bruner (1959) and Flavell (1963) are among those remaining to be convinced of the validity of this approach - it is generally conceded that the use of these models has generated much important work with substantial gains in increased knowledge about the development of cognitive processes.

The Role of Perception in Intellectual Functioning

For Piaget, intellectual functioning can be divided into two main categories. Just as reality can be conceived of as consisting of states and transformations of these states, so intelligence can apprehend either the states or the transformations. Piaget has designated knowledge of the reality states as belonging to the sphere of figural intelligence and knowledge of the transformations as operational intelligence. Operational intelligence is considered to be the basic activity in building cognitive structures and Piaget has stressed that figural intelligence can never explain new mental structures. In Piaget's view operational intelligence develops basically from interiorized actions and cannot proceed simply by a process of abstraction from perception. Pure perception is itself part of figural intelligence. One of perception's important roles in intellectual functioning is to act as a signal conveying information about reality states. Thus perception may advance or impede operational activity
slightly, perhaps by providing information that can be more or less easily processed in a given situation, but in itself cannot be explanatory for advances in cognitive development generally. In particular, perception cannot explain the acquisition of the grouping structures of the concrete operational stage, but may influence the time at which these structures can be applied to a particular content or set of objects.

Piaget believes that, in general, once the presence of a logico-mathematical structure has been inferred on the basis of cognitive behavior in a given environmental context, this same structure should be available to thinking directed toward a different context. However, Piaget has noted many exceptions to this tendency of contemporaneity of structural applications and has conjectured that in some cases perceptual factors may be influencing time differentials. In the case of operational seriation at the concrete operational stage, Piaget and Inhelder (1962) have obtained evidence that led them to conclude that there is a time lag of a year or two between the average age of acquisition of seriation of objects differing in size (perceived visually) and objects differing only in weight and identical in volume (perceived kinesthetically).

Décalage in Seriation

The Genevan term for the time lag in the application of similar thinking to different contents within the same stage
is horizontal décalage. The most familiar example of décalage is that of conservation, (the ability to recognize that quantity remains invariant under certain transformations), in which a child doesn't exhibit various conservations at the same time but typically reveals a lag of several years between conservation of amount, weight, and volume, in that order. Horizontal décalage of seriation has been investigated by Piaget and Inhelder (1962) who reported that children operationally seriate sticks at about age seven, while they cannot operationally seriate weights until about age nine. These research findings will be discussed at length below since the details are important for the present study.

Piaget and Inhelder hypothesized several possible factors contributing to the seriational décalage. The two most important causes leading to earlier seriation when differentiating visual cues are available were (1) the presence of a global perceptual field, and (2) relative ease of decenteration in the visual task.

The global visual field allows the subject to perceive the whole configuration with many simultaneous relationships. In the usual visual seriation task the subject is presented with the graduated stimuli (e.g., sticks) all at once in a disorganized array and he is asked to arrange them in order. The task can be made more difficult after seriation has been achieved by next asking the subject to insert into the series he has just constructed some new sticks of lengths intermediate
in size between adjoining elements of the first set. Some subjects who succeed in constructing the first series by trial and error will fail in the second task and will be judged not yet at the stage of operational seriation, since they are not using logical processes of co-ordinated transitive thinking. However, in both of the above seriation tasks the full configuration is in constant view of the subject and he has no problem in remembering the results of his past actions or in planning a strategy not relying on present percepts. In the seriation of weights task, on the other hand, the subject is presented with a set of objects which are visually similar and he is thus limited to successive comparisons, i.e., to obtaining knowledge of one relationship at a time since he can compare only two objects simultaneously. Consequently there is need for memory or strategy to keep track of placement of objects in a series since there is no immediate feedback concerning relationships of objects already placed in serial order.

Decentration, a recurrently important Piagetian concept in explaining cognitive growth, is the process by which the individual becomes aware of and develops the ability to take view points other than his own. Hence, individual development may be compared to a series of Copernican revolutions, starting with the infant's differentiation of himself from other people and objects.
With the advent of symbolic functioning the child must learn to differentiate subjective and objective perspectives on a representational level.

When the child reaches the stage of concrete operations (7-8 years), the decentering process has gone far enough for him to be able to structure relationships between classes, relations, and numbers objectively (Inhelder and Piaget, 1958, p. 343). Piaget and Inhelder (1962) have hypothesized that the information about many simultaneous relations available in the visual seriation context makes it easier for the child to decenter than does the successive, one-at-a-time relation required in the weight task. Decentration would make it easier for the child to understand the object relationships involved in seriation, the simultaneous "less than" and "greater than" and the transitivity operating in both directions. This perspective differs from the earlier viewing of objects only from his own point of view as "big" or "little". However, there has been no investigation of whether the ability to decenter object relationships in visual seriation continues to depend on the availability of information from the global perceptual field. If this dependency exists it might be expected that, deprived of global visual cues, the ability to seriate visually would lose its time advantage over weight seriation and both operations would appear in the child simultaneously. If, on the other hand, once decentration has occurred the multiple perspectives remain cognitively available regardless of
immediate context, then deprivation of global cues would not decrease visual seriation performance and it would retain its temporal advantage over weight seriation. In the former case availability of perceptual cues alone could explain the horizontal decalage; in the latter case some other concept, perhaps decentration, would be needed.

In a later discussion of seriation décalage Inhelder and Piaget (1964) maintained, somewhat in opposition to their earlier work, that globality of the perceptual field is sufficient to explain décalage between seriations. In this case they were concerned with the décalage between visual and tactile seriations. They compared seriation performance with sticks visually perceived and sticks hidden from view but manipulable. The authors maintained that lack of global cues is responsible for the lag of about two years in tactile operational seriation. Several questions, however, remain unanswered. Why is the operational strategy not applied to the tactile task when it is already available to the child for the visual task? Inhelder and Piaget conjectured that the operational strategy is not an efficient one in the tactile case, but more work needs to be done here, perhaps in setting up tactile tasks where it would be efficient to use operational strategy and see if it is available to subjects.

Inhelder and Piaget chose the tactile task in order to eliminate global perceptual cues but this task does not seem to have accomplished the purpose. Although the tactile task
does not provide immediate global visual cues, the experimen-
tal report indicates that many children used global tactile
cues by holding all the sticks (ten of them) simultaneously in
their hands. It seems that the weight seriation task
investigated in the earlier work provides a better test of
the non-global perceptual cues. This returns us to the previous
question of whether perception alone can explain the decalage
or whether it is necessary also to invoke some other explana-
tion like decentration.

The present study investigated the role played by
perception in the décalage between visual and weight seriation
by attempting to equate perceptual cues available in both
tasks. Age of mastery of seriation in the two modalities could
then be compared and any differences in time of acquisition
would then presumably not be due to differences in perceptual
factors.

Strategy

From his empirical work with seriation ability, Piaget
has concluded that operational seriation typically manifests
itself by the use of one particular strategy of problem
solving. According to Bruner, Goodnow, and Austin (1956)

A strategy ... is a description of extended
sequences of behavior ... if behavior is to
be viewed as strategy the task of analysis
can only be accomplished by devising experi-
ments that can get a lot of sequentially
linked behavior out of the organism where it
can be observed.
The seriation strategy that Piaget has described is that of choosing on the basis of all possible comparisons first the object at one extreme of the series (say the heaviest), then the heaviest of all those remaining, and so on until the end of the series is reached. This strategy is somewhat analogous to Bruner's conservative focusing strategy in concept formation. As applied to concepts, when the S has been shown a positive instance of a concept with immediate feedback following each choice, he proceeds by altering aspects of only one attribute at a time. Thus, after each choice he receives information as to the relevance of the attribute changed. By holding on to the positive instance the memory load is kept to a minimum and at the conclusion of testing all hypotheses the S remains in possession of a positive exemplar of the total concept. In the seriation task the S need keep track only of the objects he has not yet tested and he can constantly retain the heaviest of all those tested so that at the conclusion of a round of comparisons he is in immediate possession of the desired object. We shall designate this strategy in the case of seriation as "iterated focusing" since the focusing process must be iterated to find the next heaviest object, etc.

Although Piaget has called the strategy of iterated focusing the hallmark of operational seriation, he has provided no detailed evidence as to how many Ss actually used this strategy. In no case has he discussed how the judgments
were made by the E to decide what strategy an S was actually using, or if there were difficulties involved in making these judgments. The present research was designed to provide some data on the availability and use of iterated focusing by structuring the task to make the operational strategy the only workable solution (insofar as this was possible). Careful notations were recorded on a data sheet developed for this purpose indicating the exact type and number of comparisons made by each S. From these data it was possible to make inferences about the strategies Ss were actually using and to state the behavioral criteria used for making these inferences.

Seriation of Weight Studies

The seriation of weight tasks with children aged 4 to 10 previously alluded to (Piaget and Inhelder, 1962) will be discussed briefly here because of both their relevance to the present research and their unavailability in English translation. The actual tasks used were of two main types, one of which allowed the child to handle without restriction the objects to be seriated (stones, balls of clay); the other forced the child to compare the objects only two at a time. During the comparisons each object had to be placed in one of two identical topless boxes. The former tasks will henceforth be designated "free" while the latter will be called "constrained". The restrictions on the constrained tasks were designed to prevent the child from relying on kinesthetic
memory of weights which could allow him to achieve seriation without relying on logical thinking. Piaget's interest is not in successful seriation performance *per se* but rather in the development of the ability to use logical means of solution of the task. He was not particularly concerned with the discriminability of the weight differences between stimuli because the children were allowed to use beam balances if they so chose. No data were provided concerning the actual use made of the scales. Of the five main tasks performed by the children, three are of special interest to the present discussion: (1) constrained weight seriation of three objects with volumes uncorrelated with weight, (2) free seriation of 10 objects of equal volume, (3) constrained seriation of 4 to 6 objects of equal volume.

Piaget found that children at about 9½ years could solve both the constrained seriation of 3 weights and the free seriation of 10 weights using iterated focusing, but were unsuccessful in constrained seriation of 4-6 objects. He speculated that the solution of the latter task presupposed an order of succession planned in advance by the subject. Not until children could solve this more difficult task together with some quasi-verbal 3-term seriation tasks did Piaget consider that they had attained operational seriation of weight. No specific average age was attached to this stage, although from individual protocols given as examples it seems to be at about 10 years.
In a later work, Inhelder and Piaget (1964) referred to seriation of weights as following seriation of visually perceived objects by about two years. However, the exact nature of the seriation tasks involved was not specified so the comparison is of limited usefulness. This is particularly true since it is conceded by Piaget that both the number of elements to be seriated and the size of differences between adjoining elements in the series affected seriation performance; these findings were corroborated by Elkind (1964).

The interpretation of the visual-weight comparison is equivocal for several other reasons as well. The constraints which Piaget put on some of the weight tasks seem to be logically more stringent than those he placed on the visual tasks. The unknown extent to which the beam balance was used makes it difficult to evaluate how much the visual comparisons were indirectly involved in the weight tasks. These difficulties point up again the necessity of specifying the context in which a given task is performed, as well as the logical requirements of the solution. Flavell and Wohlwill (1969) have presented a model which takes task difficulty specifically into account. This model will be discussed below. Finally, the weight experiments omit a discussion of the methodological procedures involved in a very important variable, i.e., how the strategy used by the subjects was actually evaluated.
Statement of the Problem

The present problem was to investigate the development in the stage of concrete operations of the use of an operational strategy (iterated focusing) to solve two seriation tasks, one involving lengths (perceived visually), and the other involving weights, (perceived kinesthetically.) Comparisons of development could then be made between the two modalities. Global perceptual cues and immediate kinesthetic memory were minimized in order to insure, insofar as possible, that logical processes would be used for the seriation solutions. The tasks were designed to evoke observable strategies which could be scored reliably for degree of logic, with some confidence that the behavior could be validly interpreted as a reflection of the actual plan being executed by the S. The S's verbal description of his plans could be used as one important though admittedly not infallible indicator of the desired isomorphism between observed behavior sequence and actual plan. Attempts were made to insure that all stimulus objects were discriminably different from one another within modalities and that ease of discrimination was approximately equal for visual and weight stimuli, in order that perceptual discrimination might not becloud the principal strategic considerations.
METHOD

Subjects

Sixty-four boys and girls, students in Page Elementary School in Boone, Iowa, participated in the experiment. There were eight boys and eight girls from each of grades 2, 3, 4, and 6. The mean ages were respectively 8 years, 2 months; 9 years, 2 months; 10 years, 0 months; and 11 years, 11 months. The children were largely from the middle class with mean IQ (Kuhlmann-Anderson) of 120, based on the only available test results which had been obtained from about half of the Ss. The original design called for the first three grades only. However, when it became apparent that the tasks were too difficult for these young Ss, sixth-graders were added. The fifth-graders of Page School were not used as Ss because they were participating in a city-wide testing program during the week that the experiment was in progress. According to the principal this fifth-grade class was unusually advanced intellectually as measured by standardized aptitude and achievement tests and hence might not have been comparable to students from the other grades who were more homogeneous on intellectual measures. Hence, no special effort was made to

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1The author is indebted to Mr. Arthur Blue for arranging a school interview and to Mr. Boelman, principal, and the teachers and staff of Page School who were uniformly extremely helpful and co-operative during the course of the experiment.
obtain experimental data from fifth-graders.

**Pilot Studies**

Pilot studies were carried out with different Ss to insure that (1) the stimuli were reliably discriminable, (2) the instructions were comprehensible, and (3) the data sheet was workable. Instructions and data sheets were both revised and retested during the pilot studies.

**Materials**

Stimuli to be seriated were 12 plastic cylindrical pill containers (called cans) each 3½" in height and 2" in diameter and painted flat black. These containers had white plastic screw-top lids. The six cans used in the weight task (Task W) were filled with lead shot and cotton to form a series of weights (in grams) as follows: 314, 115, 248, 420, 648, 1020 and will be designated henceforth as numbers one through six in the above order. This series represented a pragmatic attempt to take into account Weber's law, within the limits of the stimuli used and the weight discrimination ability of similar subjects as tested in a pilot study. Note was also taken of Robinson's (1964) findings that similar stimuli (within weight ranges of the 3 lightest of the present stimuli) could be reliably discriminated within 90 grams of each other by children of the same age as or younger than those to be used in the present experiment.
Of the six cans used for visual seriation (Task V), each had a vertical white plastic stripe 3/8" wide pasted to the base and extending upward in length (in inches) as follows: 1/2, 3/4, 1, 1 1/4, 1 1/2, 1 3/4. These lengths are comparable to those used by Elkind (1964). The white stripes were covered by strips of black elastic each 3/4 inch wide and 2 7/8 inches long. The elastic was fastened only at the top by a 3/4 inch long black plastic strip (3 inches wide). This elastic covering prevented a view of the white stripe unless the elastic was lifted, which the S was allowed to do only when comparing two cans.

Two plastic lazy susans (called turntables) 10 1/2 inches in diameter and 5 1/2 inches in height, each double tiered, were used in both tasks. The lower tier of each turntable could be used by Ss to store cans which were not being currently compared. Two turntables were provided so that Ss might keep separate those cans which they had already compared from those not yet compared. The turntables were curtained with bright red terry cloth to provide visual appeal while preventing the S from using positional cues regarding placement of the cans already compared. Rotating of the turntables after placement of cans within also prevented the use of positional cues.

Six white plastic cups arranged in a row were used as receptacles for the cans after Ss had determined the proper serial positions. The cups were 3 1/2 inches high and 2 3/4
inches in diameter across the top, tapering to 1 3/4 inches in diameter across the base.

A box six inches long by three inches wide by three inches high, covered with red terry cloth for visual appeal, was used as a container for the two cans which the S was about to compare. There was a red terry cloth-covered lid which the S had to place on top of the box before he made any comparison. This requirement slowed down the comparison process and helped prevent the use of immediate memory cues.

There were several reasons for limiting the number of elements to be seriated. Pilot studies had established that six was the largest number of pill bottles which could be reliably discriminated, using the lead shot and cotton filler. It was judged desirable to use the pill bottles and filler since they were of a handy size, readily available to other investigators and had been tested for discriminability within part of the present weight range by Robinson (1964). Piaget and Inhelder (1962) had determined that six elements were sufficient in a constrained context to establish whether or not task solution involved logical processes. Stimuli were also limited in number in order to prevent the tasks from becoming too tiring or boring.

Procedure

The S stood at a table with the covered box directly in front of him containing 2 cans (#3 and #4). The white cups
were placed in a row behind the box with the two turntables on either side of the box. The remaining four cans were placed within the lower tier of the left-hand turntable. The S was informed that they were there. Instructions (Appendix A) were memorized by the E and delivered to each S orally before each task. The S was allowed to compare only two cans at a time. After each comparison he had several options: (1) he could return both cans to either turntable; (2) he could keep one and return one to either turntable; (the turntable was rotated after each comparison) or (3) he could place one or both in the white cup(s) if he had decided on their final serial positions. Once he placed a can in a cup he could not remove it. This restriction was to prevent solution by trial-and-error. Operational seriation would be exhibited if the S always retained one can and returned the other one to the turntable containing cans already compared. The can retained must be the one at an extreme end of the series of those already tested—e.g., heaviest or longest. This is the iterated focusing strategy. The task was continued until all six cans were placed in the six cups.

At the conclusion of the presentation of the task instructions, the S was asked to describe it in his own words. Corrections were made as necessary. During the course of the task any tendency toward making an unallowed move was forestalled as soon as possible. In particular, many Ss had to be reminded initially to place the two cans in the box,
cover it, and then remove the cover before proceeding with the comparison. Ss were timed for performance of each task; the number of comparisons made was recorded, the disposition of cans after each comparison was noted together with the order of placement of cans. A data sheet (Appendix A) was used to record information. Each S was tested on both tasks.

If the S placed the cans in incorrect serial order in the cups on either task, at the conclusion of both tasks he was asked to seriate the stimuli freely for the task(s) failed. This was to ascertain if the stimuli were discriminable to him.

At the conclusion of object manipulations Ss were asked which task was easier for them and why. They were then asked (separately for each task) to describe what sort of plans they had had for carrying out the experimental seriations.

Subject Selection and Data Collection

Data were collected by the E and an assistant E (a fellow graduate student) working as a team over the period of a week in the Page Elementary School in Boone, Iowa. The E was initially provided with a list of all students in grades 2, 3, and 4. From this list Ss were chosen at random by assigning numbers to the Ss by grade and sex and drawing correspondingly numbered poker chips from a box. The restriction was made that there be 16 from each class (8 boys and 8 girls) and that once an S was chosen, his siblings
became ineligible.

The actual list of names of Ss was compiled by a different assistant who had no other connection with the study, and Ss were called from their classes by the assistant E so that the principal investigator was unaware of the grade level of any S. Ss were assigned alternately to one of the two task sequences V-W (visual-weight) or W-V (weight-visual) in the order in which they had been selected with the stipulation that there be equal assignment within cells (4 boys and 4 girls in each grade assigned to each sequence). Once chosen and assigned to a sequence, Ss were randomized with respect to the order of participation.

During the course of testing this first group, it became apparent that the age range was too low to get good discrimination in operativity so an additional 8 boys and 8 girls were chosen from the sixth-graders of the same school in a manner identical to that in which the first group had been obtained. These sixth-graders then participated in the experiment under the same conditions as had the younger group.

Data were collected on a special sheet (Appendix A) and included the following information: name, age, grade, sex, sequence, birth order, time taken for each task, operativity score on each task, disposition of cans after each comparison, number of comparisons, temporal order in which cans were placed in cups, spatial order of placement, correctness of free seriation where it was required, judged relative
difficulty of tasks, as measured by responses to "which task was easier?", and post-experimental statement of how the Ss had executed the seriation. The E explained the tasks, monitored the performance, and kept track of the number of comparisons made; the assistant E recorded the remaining data.

**Scoring**

Each S was assigned three operativity scores, one for operativity on the visual seriation task $(V^p)$, one for the weight seriation task $(W^p)$, and a sum score for total operativity $(V^p + W^p)$. The possible range of scores on each individual task was from one to four and on the sum scores from two to eight. Scoring criteria were set up by the E and protocols were then scored independently by the E and the assistant E. Of the 128 judgments made there was disagreement on only two scores and the difference in each case was only one point. A score of four (complete operativity) was assigned only to those Ss who carried out the seriation by systematically testing the stimuli in pairs, in turn taking stimuli from one turntable and placing those already tested in the other turntable, always retaining in the box the heaviest (longest) of all stimuli tested in that round. This retained element will be designated the "anchor" element. Upon conclusion of a round of testing (signaled by an empty turntable) the last can was placed in the next empty cup in the series and the process was repeated, reversing the roles
of the turntables. The above is the behavioral description of iterated focusing within the context of the present experimental situation.

Ss who started out with iterated focusing for one round but then failed to carry it through (usually resorting to judgments based on memory or occasionally attempting to use only one turntable for the entire process) received a score of three points. All the aforementioned Ss reported awareness of an operational plan by stating in the post-experimental inquiry that they always kept the anchor element. Several Ss who received a score of three reported and executed not the iterated focusing strategy but instead a spatial strategy which consisted of placing the heaviest (longest) cans in one turntable and the lightest (shortest) in the other. This plan involved a breaking up of the original task into two smaller sub-tasks.

Two groups of Ss received scores of two points. One group reported awareness of always keeping an anchor can and showed behavior which included actually retaining a can in the box after at least three comparisons. However, this group failed to carry out even the first round in a completely operative fashion. The other group receiving two points exhibited logical behavior to the point of testing all six stimuli before making any placement of cans. Ss failing to meet any of the above criteria received the minimum score of one point.
Experimental Design

Half of the eight boys and half of the eight girls from each of grades 2, 3, 4, and 6 were assigned to sequence V-W; the other half to sequence W-V. Those Ss in V-W did the visual seriation first and then the weight seriation. Ss in W-V performed the tasks in the reverse order. Ss in both groups then performed the free seriation on any modality which they had not seriated correctly during the experiment-proper. All Ss were subsequently asked which experimental task they had found easier and why. They were then requested to divulge any plan or plans of task execution which they might have had in mind during the experiment.

Statistical Treatment

The statistical analyses of variance involved three independent variables all with fixed effects: sex, grade, and sequence. Analyses of variance were computer analyzed and tested for significance beyond the .05 level. The dependent variables were visual operative seriation, weight operative seriation, the sum of the two preceding seriation measures, and subjective judgment of relative task difficulty. All of the above analyses of variance were computed for all Ss (N=64). In addition, similar analyses of variance were computed for the sixth-grade alone (N=16, with the omission of the grade variable. Analyses of covariance were also computed for the
sixth-graders with IQ as the co-variate.

Correlation coefficients were computed among all the variables on which data were collected. Separate tables were obtained for all Ss (N=64); sixth-grade Ss only (N=16); and second-, third-, and fourth-grade Ss (N=48).

Hypotheses

Hypothesis 1 was that there would be significant differences between performance on visual operativity and weight operativity, with the advantage to the former. The null hypothesis 1 stated that operativity scores would either be equal or that weight operativity would be superior.

Hypothesis 2 was that increasing grade would exert a significant positive effect on both kinds of operativity. The null hypothesis 2 was that grade would either have no effect on operativity or that increasing grade would have a negative effect on operativity.

Hypothesis 3 was that there would be no significant sex difference on either measure of operativity. The null hypothesis 3 was that either boys would be significantly more operative or that girls would be superior.
sixth-graders with IQ as the co-variate.

Correlation coefficients were computed among all the variables on which data were collected. Three separate tables were constructed for (1) all Ss (N=64); (2) sixth-grade Ss only (N=16); and (3) second-, third-, and fourth-grade Ss (N=48).

Hypotheses

Hypothesis 1 was that there would be significant differences between performance on visual operativity and weight operativity, with the advantage to the former. The null hypothesis 1 stated that operativity scores would be equal.

Hypothesis 2 was that increasing grade would exert a significant positive effect on both kinds of operativity. The null hypothesis 2 was that grade would have no effect on operativity.

Hypothesis 3 was that there would be no significant sex difference on either measure of operativity. The null hypothesis 3 was necessarily of the same form as hypothesis 3. However it was expected in this case that the null hypothesis would not be disconfirmed.
RESULTS

Possible Modality Differences in Operativity

In order to compare visual serial operativity ($V_{op}$) with weight serial operativity ($W_{op}$) and to investigate their relationships to other variables, analyses of variance were computed from the Aardvark computer program on the IBM 360-65 computer for all Ss ($N=64$). The dependent variables were $V_{op}$, $W_{op}$, and $V_{op} + W_{op}$, each taken separately. In all cases the independent variables were sequence, sex, and grade level. A t test was carried out between the means of $V_{op}$ and $W_{op}$, and a full computer-derived table of Pearson r correlation coefficients between the operativity variables and all other variables described above in the section on data collection was obtained. Those correlation coefficients which were statistically significant appear in Table 1.

All the evidence led to the conclusion that $V_{op}$ and $W_{op}$ followed essentially the same course of development from second to sixth grades. The analyses of variance showed that both operativity measures had a highly significant main effect due to grade level (for $V_{op}$ $F=17.2$, $df=3, 48$; for $W_{op}$ $F=15.3$, $df=3, 48$; both significant beyond the .001 level). Both operativity measures also had a significant sex x sequence interaction (for $V_{op}$ $F=5.97$, $df=1, 48$; for $W_{op}$ $F=6.43$, $df=1, 48$; both significant beyond the .05 level.) Other effects were not
Table 1. Significant correlation coefficients for N = 64

<table>
<thead>
<tr>
<th></th>
<th>V_{op}</th>
<th>W_{op}</th>
<th>V_{op} + W_{op}</th>
<th>JDD</th>
<th>Grade</th>
<th>Age</th>
<th>V_{CS}</th>
<th>W_{CS}</th>
<th>Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{op}</td>
<td>1</td>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W_{op}</td>
<td>.90</td>
<td>1</td>
<td>.98</td>
<td>.97</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_{op} + W_{op}</td>
<td>.98</td>
<td>.97</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JDD</td>
<td>-.28</td>
<td>-.29</td>
<td>-.29</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade</td>
<td>.55</td>
<td>.55</td>
<td>.56</td>
<td>-.27</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.60</td>
<td>.57</td>
<td>.60</td>
<td>-.28</td>
<td>.94</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_{CS}</td>
<td>.56</td>
<td>.52</td>
<td>.55</td>
<td>-.45</td>
<td>.33</td>
<td>.30</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W_{CS}</td>
<td>.55</td>
<td>.47</td>
<td>.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.36</td>
<td>1</td>
</tr>
<tr>
<td>Sequence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.36</td>
</tr>
</tbody>
</table>

\( ^a \) 2-tailed \( r \) significant .05 = .24, 2-tailed \( r \) significant .01 = .31. df = 62.

\( ^b \) Visual operativity = \( V_{op} \).

\( ^c \) Weight operativity = \( W_{op} \).

\( ^d \) Sum of 2 operativities = \( V_{op} + W_{op} \).

\( ^e \) Judged differential difficulty of tasks = JDD.

\( ^f \) Correctness of serial placement for \( V_{op} = V_{CS} \).

\( ^g \) Correctness of serial placement for \( W_{op} = W_{CS} \).

Statistically significant, save for the sex x sequence x grade interaction which barely attained significance at the .05 level for \( W_{op} \) only (\( F=3.53, \) df=3,48). This difference in interactional significance, for reasons to be discussed below,
was not considered to be of sufficient importance to warrant belief in a substantive difference between \( V_{op} \) and \( W_{op} \).

The pattern of significant intercorrelations was exactly the same for the two variables and the magnitudes were highly similar in all cases. A two-tailed \( t \) test between means yielded an insignificant difference (\( t = .5, \) df=62). The obtained \( r \) between \( V_{op} \) and \( W_{op} \) was .90. Only 11 out of the 64 Ss obtained scores on \( V_{op} \) and \( W_{op} \) which were not identical. Of these 11 Ss only one obtained a score differential greater than one point, that being a two point difference.

Hypotheses

Since there were no significant differences in operativity between modalities, null hypothesis 1 cannot be rejected; hence, hypothesis 1 was disconfirmed.

The highly significant effect of grade level on operativity provided evidence in favor of rejecting null hypothesis 2. Accordingly, hypothesis 2 was confirmed.

The lack of significant differences in operativity due to sex differences made it impossible to reject null hypothesis 3. This lack of rejection was predicted in hypothesis 3.

Operativity as a Unitary Concept

Since no evidence had been obtained to demonstrate meaningful differences between the two kinds of operativity,
Table 2. The relationship between operativity scores and grade - number of subjects at each level

<table>
<thead>
<tr>
<th>Grade</th>
<th>Operativity Sum Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2,3, or 4</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

the Ss summed operativity scores were used to investigate the course of general operativity. Table 2 illustrates the outstanding characteristic of summed operativity (i.e., its increase with higher grade levels) by showing the increase in the number of Ss who showed operational behavior as grade level increased. For the purpose of illustrating this change, Ss have been divided into two groups, one of which showed little or no operativity (sum scores of 2, 3, or 4) and the other moderate to complete operativity (sum scores of 5, 6, or 8; no S having received a score of 7). All of the Ss of the latter group had at least one "3" on an operativity task while only one S in the former group attained a "3". Hence, this group division criterion appeared to differentiate essentially-operative from essentially-non-operative Ss. From this table it can be seen that Ss in second and third grades were alike in showing little or no operativity while fourth-graders showed some small increase. However, it was only among sixth-graders that a substantial amount of operativity was observed. Indeed a correlation coefficient
based on N=48 (2nd, 3rd, and 4th graders) was insignificant between grade and summed operativity. On the other hand, for N=64 there was a highly significant (.56) correlation between these variables as was demonstrated in Table 1.

Despite the dramatic increase in operativity over grades, only 6 out of 16 sixth-graders exhibited complete operativity. Under the less stringent requirement of scores from 5 to 8 points only 11 of the sixth-graders (69%) were operative. Operativity as operationally defined by performance in the present experimental task has, then, not yet been achieved by the present sixth-graders as a group.

Sex x Sequence Interactions

Both $V_{op}$ and $W_{op}$ showed significant sex x sequence interactions, although neither main effect was significant. There remains the possibility that the significant interaction may have served to obscure the actual importance of these two variables. In order to investigate the possible magnitude of these effects an estimate of the percentage of variance attributable to the sex x sequence interaction was calculated. The finding that only 5% of the total variance could be accounted for by the above interaction compared with 43% due to grade effects made it likely that sex and sequence were not of paramount importance in the present study. The nature of the interaction for $V_{op}$ $W_{op}$ is shown in Figure 1, where it can be seen that boys in V-W scored higher than boys in W-V, while the reverse trends (to a lesser degree) were shown by the girls. While no conclusive reason can be offered for this phenomenon there is some evidence that IQ may have some explanatory value in this context. The
random process of selection of Ss may have resulted, by chance, in a systematic IQ (as measured by Kuhlmann-Anderson) bias among the boys in sixth grade where most operativity was observed. This bias may then have been responsible for the elevated operativity of boys in V-W (who had IQ's above the mean) and lowered operativity of boys in W-V (who had IQ's below the mean). This explanation rests on the assumption that IQ was affecting operativity and some evidence to this effect will be presented below.

The four sixth-grade boys in sequence W-V (mean IQ 118) received a mean operativity score of 3.5 points; the four sixth-grade boys in sequence V-W (mean IQ 130) all showed complete operativity, i.e., a mean operativity score of 8 points. The mean IQ for all sixth-graders was 125 and their mean operativity score was 5.7. Hence, there is reason for believing that both IQ's and operativity scores were atypical in the direction which might produce the significant interaction that was obtained.

In addition, there is evidence that IQ was influencing the sex x sequence interaction among sixth-graders. An analysis of variance of sum operativity among sixth-graders (N=16), with the independent variables being sex and sequence, revealed a significant sex x sequence interaction (F=11.1, df=1,12; significant beyond the .01 level). However, when IQ was used as a covariate in an analysis of covariance this significance disappeared (F 1). This explanation is, of course post hoc
and tentative and must await future verification which might come indirectly in the possible finding of no significant sex x sequence interaction in situations where IQ effects had been effectively randomized. It should be noted here that IQ's were not available for non-sixth-graders in sufficient numbers to allow for their statistical use. A table of intercorrelations was computed for sixth-graders alone but none of the IQ correlations was statistically significant, indicating that, at least in this group, IQ was not very influential.

**Triple Interaction**

The sex x sequence x grade interaction was significant for \( W_{op} \) but not for \( V_{op} \). The differences between the two interactions are listed in Table 3 and graphed in Figure 2. The nature of the graphed interactional differences between \( W_{op} \) and \( V_{op} \) suggests that the significance of the former may be the result of several small effects, any one of which could be due to chance but which add up to produced statistical significance. (The obtained results were for \( W_{op} F=3.53, df=3,48 \); for \( V_{op} F=2.50, df=3,48 \). The \( F \) necessary for significance beyond the .05 level for \( df=3,48 \) is 2.8). The statistical significance of the triple interaction for \( W_{op} \) cannot be presently adequately explained but it seems to be of very limited importance and unlikely to be replicated.
Figure 2. Sex, sequence and grade as related to mean operativity significant for weight, insignificant for visual.
Table 3. Sex, sequence and grade as related to mean operativity - significant for weight - insignificant for vision

<table>
<thead>
<tr>
<th>Grade</th>
<th>Boys Sequence Score</th>
<th>Girls Sequence Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V-W</td>
<td>W-V</td>
</tr>
<tr>
<td>2</td>
<td>1.50</td>
<td>1.25</td>
</tr>
<tr>
<td>3</td>
<td>1.25</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>1.75</td>
<td>1.50</td>
</tr>
<tr>
<td>6</td>
<td>4.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Free Placement

Another variable which was investigated in the present study was the ability to seriate the cans used in the operational task under conditions which placed no restrictions on manipulation. All Ss who were unsuccessful in achieving correct seriation of cans in the experiment proper on either task were asked to seriate freely the cans used in the failed modality, or on both if both had been incorrect. Ss who had successfully seriated cans in the experiment proper were assumed to be able to perform the simpler free seriation task. This free seriation was required in order to be sure that Ss were not failing the experimental tasks because of inability to discriminate perceptually between stimuli. Table 4 lists by grade and modality the numbers of Ss who failed either free seriation task. No S failed both free seriations and of those nine Ss who failed one task, eight of them made only one incorrect inversion and the error appeared to be due to
Table 4. Number of subjects failing free seriation tasks

<table>
<thead>
<tr>
<th>Grade</th>
<th>Weight Failed</th>
<th>Visual Failed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*aNo subject failed both tasks.*

carelessness. One S only, aged 7 years 6 months (the youngest S in the experiment), manifested confusion about relative weights despite an apparent effort on her part to perform the discriminations; she ended with a seriation which resembled a random ordering. The overall conclusion was that the two tasks both involved stimuli which were perceptually discriminable to the Ss. The few failures which occurred were equally divided between modalities so that no differential effects were apparent in the free seriation performance.

**Correct Experimental Seriation**

A score was obtained for all Ss on correctness of serial placing of stimuli during the visual task ($V_{CS}$) and the weight task ($W_{CS}$), regardless of the strategy used in the task solution. This variable provided a rough measure of the S's ability to judge the probable range of stimuli together with an ability to remember the magnitude of stimuli already tested. In addition some degree of impulse control was essential
Table 5. Number of subjects of different grades who showed correct seriation

<table>
<thead>
<tr>
<th>Grade</th>
<th>$V_{CS}$ only</th>
<th>$W_{CS}$ only</th>
<th>Both $V_{CS}$ and $W_{CS}$</th>
<th>Grade Totals</th>
<th>$V_{CS}^c$</th>
<th>$W_{CS}^d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>5</td>
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<td>4</td>
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</tr>
<tr>
<td>6</td>
<td>3</td>
<td>1</td>
<td>7</td>
<td>11</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>

$^aV_{CS} = \text{Correct seriation for the visual task.}$  
$^bW_{CS} = \text{Correct seriation for the weight task.}$  
$^c\text{Whether only or with } W_{CS}.$  
$^d\text{Whether only or with } V_{CS}.$

since no $S$ who immediately placed the two cans in cups after the first comparison succeeded in generating correct seriation. $V_{CS}$ and $W_{CS}$ were both significantly correlated beyond the .01 level of significance with both $V_{op}$ and $W_{op}$. All four $r$'s were in the range of .37 to .7. $V_{CS}$ and $W_{CS}$ were significantly correlated with each other ($r=.36$; significant beyond the .05 level). 2 points were scored for correct seriation, 1 for incorrect.

Table 5 lists the number of $S$s who were completely successful in seriation performance. In addition to the seven $S$s who attained complete operativity and consequently completely correct seriation in both tasks, eight other $S$s were also successful in both $V_{CS}$ and $W_{CS}$. There were 18 additional $S$s who were successful in either $V_{CS}$ or $W_{CS}$ but
Table 6. Mean correct seriation scores by grade and modality

<table>
<thead>
<tr>
<th>Grade</th>
<th>Correct Seriation Score</th>
<th>Visual¹</th>
<th>Weight²</th>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>1.19</td>
<td>1.37</td>
<td></td>
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<tr>
<td>3</td>
<td>1.25</td>
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<tr>
<td>4</td>
<td>1.44</td>
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</tr>
<tr>
<td>6</td>
<td>1.62</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

¹Mean visual = 1.36.
²Mean weight = 1.37.

not both. \( V_{CS} \) was significantly correlated \((r=.33, \text{df}=62)\) with grade but \( W_{CS} \) was not. These relationships are listed in Table 6 and graphed in Figure 3.

Judged Differential Difficulty

A measure of judged differential difficulty (JDD) is based on the S's post-experimental report concerning which task was easier; possible responses being "V", "W" or "both the same" and being scored respectively, "1", "3", or "2". Two analyses of variance were calculated for this dependent variable \((N=64; N=16, \text{for sixth-graders})\) with sex, sequence, and grade as independent variables. Both analyses agreed in yielding only one significant effect, that of sequence. This main effect was significant beyond the .01 level in both cases \((F=9.84, \text{df}=1,48 \text{ for all Ss}; F=10.8 \text{df}=1,12 \text{ for sixth-graders})\). In addition, the analysis of covariance \((N=16 \text{ for sixth-graders with IQ as the covariate})\) failed to eliminate sequence as a significant variable yielding an \(F=7.5, \text{df}=1,11\)
Figure 3. Mean correct seriation scores by grades and modality
which is significant beyond the .05 level. Of the 64 Ss in the experiment 14 judged the tasks to be of equal difficulty, 22 judged V to be easier, and 28 judged W to be easier. The mean JDD score for Ss in the V-W sequence was 2.40; for W-V the mean was 1.78. Hence both groups showed a strong tendency to judge the second task as easier. This recency effect in JDD was especially pronounced for those Ss who showed some correct seriation, especially when the correct seriation occurred with the second task of the sequence which was the usual case. Of the 18 Ss who showed CS in one task only, 14 of them were correct on the second task. Of the same 18 Ss 14 of them showed recency effects in JDD and the other 4 were neutral. On the other hand, of the 31 Ss who were unsuccessful in both CS tasks, 9 Ss were neutral in JDD, 17 judged W easier and 5 judged V easier, despite approximately equal sequence distribution. The crucial variable in this group of non-correct seriators was a JDD clear choice of W as easier; whereas in the group of correct seriators the crucial variable was the choice of the latter (also correct) task. Table 7 lists the number of S's and JDD choice by sequence and grade, showing, in addition to above findings, a tendency for older Ss to prefer V. The recency effect among the correct seriators was reflected in an $r=-.45$, df=62, between $V_{CS}$ and JDD.
Table 7. The relationship of judged differential task
difficulty to sequence

<table>
<thead>
<tr>
<th>Number of Subjects in Different Grades</th>
<th>Judged</th>
<th>Judged</th>
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<tr>
<td></td>
<td>Sequence</td>
<td>Grade</td>
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</tr>
<tr>
<td></td>
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</tr>
<tr>
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<td>1</td>
</tr>
<tr>
<td>Total</td>
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<td>19</td>
</tr>
<tr>
<td>W-V</td>
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</tr>
<tr>
<td></td>
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<td>2</td>
</tr>
<tr>
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<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>9</td>
</tr>
</tbody>
</table>

Time

Although the amount of time spent on task performance
was not one of the main variables under consideration, it
was investigated because of its possible usefulness in
understanding some of the demands placed on the Ss in terms of
control of impulsivity and sustained attention.

There was no significant difference between $V_{op}$ and $W_{op}$ in
mean time taken to complete the seriation. Both means were
3.0 minutes. Nor was there any significant difference between
sexes in the mean time taken to complete both tasks: the
mean time for both sexes was 6.1 minutes. The mean time taken
to complete both tasks did, however, differ depending on the
amount of operativity exhibited; the times were 4.1 minutes
for Ss scoring 2 points, 6.9 minutes for scores of 3 or 4
points, 9.9 minutes for 5 or 6 points, and 8.8 for 8 points.
The range for the time taken to execute one task was from 49 seconds to 1\textfrac{1}{4} minutes 9 seconds. The range of performance time to complete both tasks for Ss who were completely operative was from 5 minutes 3 seconds to 10 minutes 25 seconds; for completely non-operational Ss the same range was from 2 minutes 1 second to 6 minutes 58 seconds. The range for both tasks among all Ss was from 2 minutes 1 second to 17 minutes 39 seconds.
DISCUSSION

The present experiment was successful in evoking behavioral sequences which revealed the strategies which Ss were using in the course of solving the seriation problems. The optimal solution of the constrained experimental tasks necessitated the use of a logical strategy which Piaget has described and designated "operational seriation" and which has been called in the present context "iterated focusing".

Ss at all ages showed evidence of understanding the verbal instructions and, indeed, before engaging in seriation behavior repeated (with prompting if necessary) the most important rules to be followed. These rules contained as possibilities many of the elements necessary to operational seriation (e.g., "after any comparison you may keep one can in the box") as well as some illogical alternatives (e.g., "after any comparison you may put both cans in either turntable") which could not lead reliably to correct seriation. The Ss needed to be able to choose the correct elements and synthesize them into an operational strategy.

Most of the second-, third-, and fourth-graders were unable to use operational strategies but many of the sixth-graders had considerable success, thus establishing the efficacy of the experimental manipulations if the Ss were at a sufficiently advanced developmental level.
The hypothesis that operational visual seriation precedes operational weight seriation in the stage of concrete operations turned out to be untestable in the present experiment since Ss in that stage were unable to perform successfully either task. The implications of this failure in tasks requiring strictly operational behavior will be pursued further below.

The finding that performance of operative seriation with visual cues did not differ significantly from the same task with weight cues, together with the evidence that even in grade six (S mean age of 11 years, 11 months) 75% operativity had not yet been attained, led to the conclusion that the present tasks were in the domain of formal operations, rather than that of concrete operations as had been originally hypothesized.

The age of successful performance was probably the most compelling reason for believing that these tasks were not in the domain of concrete operativity. Piaget has placed the age of attainment of this stage at from seven to eleven years, and we have seen that Ss older than these upper limits had not yet mastered the tasks. The concurrent course of development of the two modalities also fitted in well with the placement in the stage of formal operativity since it is at this stage for the first time that the physical context becomes relatively unimportant while the logical requirements of the problem situation become salient. In the present study
the logical requirements of the two tasks were identical but the contexts differed in modality.

Logical Requirements of Operational Seriation

From the standpoint of Piagetian logic it can be seen that the present seriation tasks required that the successful Ss have the ability to handle the logic of groups -- in this case, what Piaget has called the INRC group (Piaget, 1957). Briefly, the child must have mastered two logical structures; the logic of relations (specifically, the grouping of asymmetrical relations which seriation requires), in conjunction with the logic of classes (specifically, the grouping of the addition of classes). In the usual visual seriation task -- e.g., the seriation of sticks in the Elkind (1964) experiment -- the S need consider only one of these groupings at a time. He could concentrate on the asymmetrical relations (the seriation behavior) while the stimuli (all of the elements of the class) remained concretely before him, requiring no addition or subtraction of members. On the other hand, he could focus his attention on building up the class of seriated objects by looking for a new element, while those elements already seriated remained concretely before him as constantly available reminders of the asymmetrical relations already established. In the present experiment, however, while conceptualizing the serial arrangement of elements, the S at the same time had to be able to deal conceptually both with a
one-element class (the anchor element) and the class of non-anchor elements which have not yet been seriated (put into cups). Piaget has suggested that both the one-element class and classes defined in negative terms (by some attribute which they do not possess) present difficulties to children in the concrete operational stage, although these concepts are eventually mastered within that stage. He has also maintained, as noted above, that children in the concrete operational stage can deal with either the grouping of asymmetrical relations or the grouping of classes, but not with both simultaneously. One might expect, then, that children within the concrete operational stage might have mastered the elements of the present task which demanded advanced classificatory conceptualization but that they would not yet have been capable of the consolidation of the two kinds of groupings necessary for operational seriation.

Looking closely at the conceptualization requisite to carrying out a successful seriation in the present experiment and at the behavior of the Ss, it seemed likely that it was necessary for the successful S to have had a hypothesis about the structure of the problem confronting him and to have constructed a systematic plan in advance, even before he began to handle the physical stimuli. This anticipatory plan was necessary but not sufficient, as evidenced by the seven Ss who were able to articulate at least a rudimentary plan without having been able even to begin to execute it.
The ability to see the solution of the whole problem as a totality, in the absence of manipulating the physical stimuli, is one of the hallmarks of formal operativity. The younger child presumably lacks the integrative powers and the abstract ability to conceive and carry out this plan successfully.

Development of Operativity

The behavior of Ss in the present experiment revealed the course of development of the ability to seriate objects logically in a task whose successful solution demanded formal operative thinking. In order to expedite the discussion of development, Ss have been divided into four different stages which range from no operativity (stage 1) through complete operativity (stage 4).

Stage 1

Among the least advanced Ss parallels were found to the illogical behavior exhibited by younger children (aged four to five years) who were attempting to solve a simpler seriation task (Piaget and Inhelder, 1962). Piaget has maintained that children seeking to reach a given stage of development often regress to non-adaptive behaviors which they had used (and subsequently had discarded) while seeking to master an earlier developmental level. This recurrence is likely to be found when the structural demands of the earlier and later tasks are similar. In our example it is the seriational structure which is similar for Piaget's three-element task and the
present one, although the latter is more complex and hence requires an advanced cognitive solution. The behavior that is similar in the two cases is seriating the elements before all possibilities have been tested. Piaget has termed the general phenomenon of repetitive behavior patterns at different stages of development "vertical décalage" (Flavell, 1963).

The present Ss, although they were well aware and had even stated that there were six cans to be ordered and that once a can was placed in a cup it could not subsequently be moved, nonetheless blithely began by immediately placing the first two cans compared into their final cup positions. This premature placement was apparently (and according to self report) made with faith in the S's own subjective judgment as to where the cans were likely to belong. These Ss showed no decentration in this task; they seemed to act not only from a belief in their own omnipotence as judges of probability but also, in view of the great self-confidence displayed by most of them, as decreers of how the stimuli should be allocated. In addition to completely failing to display any operational strategy, none of these Ss succeeded in either correct seriation task, i.e., within the constrained task they did not produce a correct seriation, even disregarding the strategy used. However, when allowed to order the stimuli freely all Ss showed the ability to correctly seriate at least one modality and most Ss succeeded in both free seriations,
indicating that perceptual discrimination was not a problem.

It might be argued that perceptual discrimination might have been a problem during the experiment proper and that free seriation was later successful only because of the prior experience in handling the stimuli, but early pilot studies in which fifteen comparably aged children all successfully seriated the objects freely without previous experience with the stimuli makes it reasonable to suppose that the early manipulation was not crucial to success in free seriation. Hence, it has been assumed that lack of operativity resulted from inadequacy of planning and strategy rather than perceptual deficits.

The inability to act as if it were necessary to test all objects before determining the place of each in the series would be considered by Miller, Galanter, and Pribram (1960) to be a tactical deficiency. In this formulation Ss in Stage 1 did not incorporate the preliminary testing of all stimuli into their overall strategy of solution. Although these same Ss showed by later behavior in the free seriation task that they were capable of inserting this tactic (to be designated subsequently as the "test-all" rule) into the solution of a seriation task at the concrete operational level, they appeared unable to incorporate it into the more complex formal operational strategy. Presumably these same Ss had, at a younger age, been unable to insert "test-all" in the concrete-operational task, and although now having mastered it within that stage, they
were repeating the former error in attempting to solve a problem at a more advanced level.

One could also conceptualize the differences between the successful concrete-operational performance and the unsuccessful formal-operational performance of the same eight- or nine-year old child in terms suggested by the work of Flavell and Wohlwill (1969). From this point of view the "test-all" rule, while clearly within the competence system of the child (i.e., can be utilized in some contexts), can be accessed by him in the former context but not in the latter.

Clearly, if these Stage 1 Ss who were least advanced in logical thinking failed to apply the "test-all" rule, they would be unable to carry out a more complex, logical strategy, since the latter would require as a necessary first step the inhibition of the immediate-placement response. As previously mentioned, a few Stage 1 Ss, however, although neglecting the "test-all" plan, were able to formulate verbally in the post-experimental questioning the basic strategy necessary for the more logically complex iterated focusing strategy. These Ss reported their intention of always keeping the anchor element in the box despite the fact that they never actually did so. A few of these Ss even claimed to have actually carried out this plan! It should be noted that although these descriptions have been referred to as "plans" this is something of a misnomer since they partook more of the nature of hindsight than of anticipation. Although these Ss were ostensibly
reporting their pre-seriation intentions, the actual verbalizations did not occur until after the behavior had taken place. In any case, these "anticipatory hindsights" seemed to precede the ability to behave or to have behaved in accordance with the "plan". This phenomenon is analogous to Inhelder and Piaget's (1964) findings that Ss could anticipate serial configurations of sticks before they could actually carry out the seriations. In the present situation, however, Ss are using hindsight concerning strategies rather than dealing with configurations. Since Piaget has linked hindsight closely with anticipation as being the two essential components in his conceptualization of reversible thinking, it is of theoretical interest that the present experiment furnished some evidence that hindsight might play a role comparable to that of anticipation in serial behavior. In the present context there was even some suggestion concerning a mechanism which might be at least partially responsible for the inability to execute the strategy; i.e. the inaccessibility of the "test-all" plan.

Stage 2

Ss in the second stage fell into two mutually exclusive groups each judged to be showing a minimum amount of logical behavior. The first group had succeeded in applying the "test-all" rule, but beyond that showed no evidence of having a comprehensive plan for the seriation solution. These Ss typically placed all cans from memory immediately after having
carried out the preliminary testing, going through the motions of two-by-two testing but immediately thereafter placing both cans in cups.

The second group of Ss in Stage 2 manifested both evidence of "anticipatory hindsight" concerning a focusing plan and some minimum attempt at implementation of the plan, although failing to observe the "test-all" rule. From Miller's perspective the first group showed the ability to execute correctly a simple strategy based on a chain made up of identical units (designated TOTE units in Miller's terminology) but no evidence of an ability to construct a plan involving a more complex strategy; the second group showed the opposite pattern of performance, failing "test-all" but partially succeeding at focusing. It is somewhat arbitrary to consider the preceding two groups as exactly equal in logical performance, but with respect to the present experimental tasks these Ss have both been considered to be intermediate between the completely illogical Ss in Stage 1 and those in Stage 3 who exhibited both the ability to use the "test-all" plan as well as the statement and partial execution of an operational plan. Within the Piagetian framework, Stage 2 Ss might be considered to be in an early transitional stage of formal operations.

Stage 3

Stage 3 Ss, on the other hand, showed the ability to execute faultlessly the focusing strategy up to and including
the placement of the first can. These Ss were considered to be in a late transitional stage, their errors caused by an inability to iterate the focusing strategy in order to find elements of the series succeeding the first one. Binet and Simon (1929) have described behavior in a concrete operational weight seriation task in which Ss showed similar difficulty evidenced by their ability to systematically and correctly find the first element of the series by comparing all possible elements and then subsequently failing to apply systematic procedures in order to find the succeeding elements of the series. The parallel between the behavior of Binet's Ss and that of the participants in the present study provides another example of vertical décalage.

Stage 4

Ss who exhibited errorless performance in executing the iterated focusing strategy were considered to be in Stage 4. They thus showed the ability to co-ordinate logical thinking about classes with that concerned with relations. From Miller's point of view these Ss had planned and executed a highly complex strategy involving "test-all" as part of the tactics as well as the iterated aspect of the focusing strategy, i.e., the ability to reactivate the rule of "keep the anchor element" as often as necessary after having found the first element in the series.

Because the present main experimental tasks of $V_{op}$ and $W_{op}$
were in the stage of formal operativity, these variables were not appropriate for investigating possible differences in the course of development between visual and weight seriation in the concrete operational stage. However, some of the minor variables did provide some useful comparative information although all conclusions are tentative since the experiment was not designed primarily to elicit such information.

Free Seriation

Free seriation might be expected to yield some useful information for concrete operational development but, unfortunately, both the visual and weight tasks were too simple for this purpose, having already been mastered by most of the Ss. This result was not surprising for the visual task since there has been general agreement among researchers that visual seriation has already been achieved by the age of our youngest Ss. It should be noted here that our visual seriation task was somewhat more complicated than the standard visual seriation task since the different lengths of tape which were to be seriated (each of which was attached to a can) were each covered by a strip of black elastic. Thus Ss did not obtain a global view of the stimuli unless they decided to examine several cans at one time, lifting the elastcics simultaneously. The free seriation task would have allowed them to do this but it was not specifically pointed out to the Ss as a possibility. Only one S inquired if obtaining this global view
were permissible; this S then availed herself of the opportunity and obtained a correct seriation. Despite the fact that all the other Ss operated under a self-imposed restriction of looking at only two stimuli at a time, they experienced no difficulty in the visual free seriation task.

The almost universal success with the free seriation of weights was unexpected, since Binet and Simon (1929) had reported 10 years as the age of 75% group attainment of a five-item seriation of weights. There were, however, some differences between Binet's task and the present one which might help to explain the differing results. Binet's weights (matchboxes containing lead and cotton and weighing 3, 6, 9, 12, 15 grams) were considerably lighter than the present experimental weights. Binet assumed that the weights were discriminable to the children but he presented no evidence bearing on that issue; it remains possible that failure at his task might have resulted from inability to discriminate between stimuli. Binet's task had a time limit of three minutes per trial and required two successes in three trials for a passing performance. There was no time limit to the present free seriation tasks and the tasks were untimed, but subjective impressions of both the E and the assistant E were that almost all Ss performed the tasks swiftly, usually taking about one minute. Only one trial was allowed in the present tasks. These differences in time limit and number of trials are, however, felt to be of limited significance in
determining the discrepant ages of correct performance. It is considered that uncertainty of stimulus discriminability is more likely to have been a significant factor. In addition, one must consider the pervasive and probably unknowable differences in Ss in terms of life experiences between the French children tested by Binet and the present sample of U.S. children. Despite the probable hopelessness of pinning down the crucial variables affecting the age disparity it should be noted that the present younger age of U.S. children over Binet's sample in achieving criterion performance on a cognitive task is not unprecedented. The Stanford-Binet in successive revisions has moved the age placement of the carrying out of "three commissions" back a full year from Binet's original age level to its present position at four years six months.

Piaget and Inhelder (1962) reported 9 years as the age of 75% attainment of seriation of weight, as measured by performance in a free and untimed seriation task using 10 elements ranging from 100 to 250 grams, seriated in a geometric progression. In this case Piaget was not concerned with the discriminability of weights since his Ss had access to a beam balance. However, as noted above, the possible use of the beam balance introduced a source of extraneous effects into the seriation task; hence a precise assessment of the comparability of tasks is impossible.
In summary, despite indications of an older age of attainment of weight seriation in several studies, the present results indicate that in a six-element seriation task with discriminable weights as described above, Ss have already achieved 75% group success by age 8; there also remains the possibility that Ss might have achieved 75% success at an even younger age, but younger children were not tested in the present experiment so no information is available regarding the lower age limit of success.

Correct Seriation

Correct seriation measured the ability to arrange the cans in correct serial order during the constrained experimental situation, without regard to the actual strategy used. While it was true that complete operativity (use of iterated focusing) always implied correct seriation of both tasks, the converse did not necessarily hold; i.e., there did exist Ss who achieved correct seriation without showing a completely logical strategy. An examination of trends in correct seriation sheds some light on non-logical factors involved in seriation performance. Those Ss who exhibited correct seriation without complete reliance on logic apparently substituted memory of perceptual attributes for strictly logical thinking. Although the structure of the tasks - enforced successive comparisons, temporal delays, fairly narrow range of magnitude of stimuli - made reliance on memory a
risky technique and most Ss who tried it were unsuccessful, a few succeeded by some combination of luck and skill.

The most interesting feature of the performance of correct seriation was the tendency for improved performance on the second task, regardless of the modality in question. This trend was not observed in the operativity measures, leading to the conclusion that there was no increase in logical thinking over trials but there was improvement in judging perceptual probabilities in the area of skilled manipulation of physical objects. This observed difference in pattern between seriation performance and the logical processes involved in their execution points up the dangers in equating performance and process. This distinction has recently been receiving considerable attention from psychologists working in cognitive areas (e.g., Vinh Bang, 1967). In the present study Ss appeared to be able to apply their original non-logical method of task solution more efficiently to the second task, but not to be able to construct and execute a new, more logical plan for the second task. Only one S showed a dramatic increase in operativity from the first to the second task. From showing no operativity on the first task (1 point), he advanced to a late transitional performance on the second task (3 points). He was the only S to show more than a one-point differential in operativity between tasks. In contrast, on the correct seriation task 18 Ss failed correct seriation in one modality and were successful in the other.
Of these Ss 14 of them were successful in the second task only, showing a marked learning effect.

The similarity between performance on the visual and weight correct seriation tasks is especially noteworthy in view of its relevance to some of Piaget's hypotheses concerning decentration. Piaget has conjectured that the lag in the seriation of weight could not be explained solely by reference to the availability of global perceptual cues in the visual task. He maintained that, in addition to the perceptual advantage enjoyed by the visual configuration it was also easier for the Ss to learn to decenter (to be able to utilize perspectives other than their own) in the visual context. However, in the present correct seriation task where no global cues were available, there was no lag in weight seriation. In fact, there was a trend for younger Ss to do better on correct weight seriation than they did on correct visual seriation and also for them to prefer the weight seriation task. These results indicate that, at least within the present experimental context, there is no need to invoke any explanatory concepts beyond global perceptual cues since, when no global visual cues were available, there was no lag in attainment.

Time

Although operative seriation required some initial impulse control (to avoid placing cans in the cups immediately)
and the ability to execute a sustained strategy for several minutes, the time requirements for successful performance did not seem to be a problem for the Ss. In fact, as has already been noted, totally operational seriation was less time-consuming on the average than partially operational seriation. Once the S appeared to be operating under a firm iterated focusing strategy the task appeared to become routinized, unstressful, and seemingly non-fatiguing. Ss at an intermediate level, on the other hand, occasionally showed signs of stress or fatigue when the task execution showed some signs of disintegration. Some of these Ss experienced difficulty in ending a given pattern of behavior and initiating a new phase.

In Miller's terminology these Ss were not effectively applying the second "test" of the "TOTE" unit, and hence were having trouble exiting from the type of behavior in progress. This type of inefficient behavior has been designated "loss of hold" by Donaldson (1964). A specific example from the present is the performance of those Ss who used a focusing strategy to test all cans in one turntable, in the process placing all non-anchor cans in the other turntable. Upon completion of this round of testing these Ss failed to recognize that the can remaining in the box was the anchor element and should be placed immediately in the next empty cup of the series. Instead of making this placement Ss continued to re-test the same elements, transferring them after each comparison into the original turntable. These Ss might
then understandably become tired of what had become an unending loop and they might eventually exit by placing cans by memory or some seemingly illogical process. These Ss in transitional stages of operationality were the only ones whose behavior appeared to be adversely affected by the temporal demands of the tasks, and the difficulties were due to inefficient task execution. On the whole the time and attention requirements of the tasks seemed to be within reasonable limits for the participating Ss. The restriction of the series to six elements apparently was successful in cutting down on time demands while still insuring that sufficient behavior would be elicited so that its logical attributes could be assessed.

Judged Differential Difficulty

Some evidence regarding Ss' reactions to the tasks was provided by their answers to the question "which task was easier?" As we have seen there was a statistically significant difference in responses to this question on the basis of sequence. Ss judged the second task to be the easier of the two, and also performed the correct seriation more successfully on the later task. However, there were no significant sequence effects in operativity, indicating that Ss' logical thinking had not improved along with the improvement in their manipulative skill. The experiment was thus successful to
some degree in separating processes of logical thought from actual seriation performance. The subjective judgment of the difficulty of the task appeared to be linked with performance rather than logical variables.
CONCLUSION

Within the context of the present study children in the stage of concrete operations (second-, third-, and fourth-graders) succeeded in seriation tasks using visual cues or weight cues when there were no constraints on handling the six objects to be seriated. This unconstrained seriation performance was exemplified by behavior in the post-experimental free seriation tasks. These same children failed in both modalities to exhibit logical, operational methods of solving a seriation task involving the same six objects when strict constraints were placed on the manipulation of objects. These logical solutions involving iterated focusing methods of seriation were studied in the experiment proper under the very strict constraints described above. Even sixth-grade Ss did not show sufficient operative behavior to be considered as a group to have achieved success on the latter tasks. It appears then that children could not succeed in completely operational seriation in either modality until they were well into the stage of formal operative thinking. From this viewpoint any partial logical restrictions (such as those which Piaget placed on seriation tasks) seem arbitrary and hence these partially constrained tasks should not then be used to define "operational" performance with age norms of accomplishment derived therefrom. Specifically, Piaget put certain constraints on visual seriation tasks (namely, the ability to insert new
elements into already constructed series) and Ss had to perform these additional seriations before they were considered to have achieved operational seriation using visual cues. He also put constraints on weight seriation tasks (comparing weights only two at a time in a situation where kinesthetic memory was deliberately made difficult, with the use of beam balances necessitated in some of the discriminations) and Ss were considered to have achieved operational seriation of weights only if they exhibited correct seriation under these conditions. Piaget then concluded that, based on these arbitrarily constrained tasks, Ss achieved visual "operational seriation" several years before they could succeed in performing "operational seriation" of weights.

The whole concept of logical "operational seriation" together with other such global, context-free capabilities, may not be a fruitful one in the stage of concrete operations where, as Piaget himself has emphasized, the physical context is of enormous importance. It might be potentially more rewarding to compare which visual and which weight seriation tasks, with careful attention to specifying contextual constraints, children of certain ages or stages can successfully perform. This comparative, developmental approach would be very much in the spirit of Flavell and Wohlwill (1969) who have been working to develop potentially predictive and presently at least descriptive equations involving the same variables under discussion here.
Logical task specifications seem much more meaningful in the realm of formal operations where the physical context has been assumed to be much less important. In this later stage one might expect modality differences (since they represent differences in physical context) to be relatively unimportant. These expectations received some support from the present study.
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**IF EITHER TASK FAILED WAS FREE PLACEMENT SUCCESSFUL?**

**TASK 1:**

**TASK 2:**

**SOLICITED COMMENTS:**

WHICH TASK EASIER

HOW DID YOU DO TASK 1?

HOW DID YOU DO TASK 2?
INSTRUCTIONS (delivered orally)

Pre-experimental Instructions for Sequence W-V, Task W.

I have a couple of sets of cans that I'd like you to arrange in a series. Lift these cans. See, one is heavier and one is lighter. Which one is heavier? Which can is lighter? Right! Now, I don't think you'll have any trouble telling which can is heavier, but if you ever do you can switch the cans to the other hands. Do that now and tell me which seems heavier. (S performs exchange) Is it still the same one? Good!

There are six black cans with different weights which you are to place in these six white cups. Two of the cans are here in front of you and the other four are in this turntable. (E indicates the left turntable; the cans are not visible, being inside the curtained turntable on the lower tier.) "You are to place these six black cans in these six white cups so that you end up with the heaviest here" (points to extreme left cup). The one that's just a little bit lighter here, then a little bit lighter ... until finally you have the lightest one in this cup (indicates extreme right cup). Once you've put a can in a cup you can't take it out again, so be sure you know which cup a can belongs in before you put it in.

There are a few rules to follow while you're doing this. You can only lift the cans two at a time to find out which is
heavier and which is lighter, and you'll probably want to make quite a few weighings while you're finding out where the cans belong. For each weighing you must first place the two cans in this box and close the cover. The reason you put the top on each time is to slow you down because I want you to take your time while you're doing this and putting the top on the box is a good way to remind you to take your time. Then you take off the cover and lift up the cans to see which is heavier and which is lighter. You can change hands if you want to, to help you decide. After you're through lifting them you have several choices of things you can do. You can put both cans in the turntables or cups or you can put one can in a turntable or cup and keep one in the box. (demonstrates these actions) If you have put both cans away, then you take two new ones from a turntable and put them in the box to get ready for a new weighing. If you put one can away and kept one in the box, then you take a new can from a turntable and put it in the box to get ready for a new weighing. After you've put a can in a turntable, give it a spin so you won't be able to remember where you put it. There is no time limit and you can make as many weighings as you need to, to decide what cup a can belongs in. You can keep on going as long as you need to, putting cans in and taking them out of different turntables if you want to until you have all the cans in the cups. Any time you've decided where a can belongs you can put it in a cup but once you've put a can in a cup you can't move it any more. When you've put each can in a cup, you've finished and you
should have them in order from the heaviest here, the next heaviest here and so on until you have the lightest one here.

Now, remember, (demonstrates the following) first place two cans in this box - close the cover, then lift the cans and weigh to see which is heavier and which is lighter. Put one or both in the turntables or cups. Spin the turntable. Take a new can or cans from a turntable and put in the box and you're ready to start again.

Any questions? (If there are questions these are answered). Now will you tell me in your own words what you're supposed to do? (Any misconceptions are corrected and prompting is used to elicit information about any omissions in the behavioral description).

Instructions preceding Task V.

Now look at these two cans. (E lifts elastic and demonstrates) See, one has a longer white stripe than the other. There are four more cans in the turntable with different length stripes, making six cans altogether. Now, you're going to arrange them in order just like the other cans, only now you'll put the can with the longest stripe here, the one with the next longest here, and so on until you put the one with the shortest stripe here" (E indicates the cup on the extreme left, and on the extreme right respectively,) We have the same rules as last time. First put two cans in the box, and close the cover. Then take out the cans, lift the black elastic and
see which has the longer stripe and which has the shorter. I don't think you'll have trouble deciding but if you do you can hold the stripes close together. Then put one or both cans in the cups or turntables. Once you put a can in a cup you can't move it any more. Keep going until you decide which cup a can belongs in, then put it in and keep going until you have all the cans in the cups with the longest here and the shortest here.

Instructions for V-W are the same as above, with appropriate changes for different modalities.

Instructions for Free Seriation (in the event of incorrect experimental seriation). Now, you can put the cans in order on the table with the lightest one here, the one just a little heavier here, and so on with the heaviest here. There aren't any rules this time. You can handle the cans any way you want to.