ABSTRACT

A DEVELOPMENTAL STUDY OF VISUAL AND

HAPTIC PERCEPTION OF FORM

By

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The intent of this research was to test certain hypotheses implied by theory and past research concerning the development of cross-modal (inter-system) perception of form in vision and touch. One hypothesis (Hebb, 1941; Birch & Lefford, 1963; Rudel and Teuber, 1964) was that developmental change in visual-haptic inter-system perception is due to change in visual or haptic perception alone. A second hypothesis (Piaget and Inhelder, 1956; Pick, 1964; Hebb, 1949; Gibson, 1966; Gibson, 1969) was that developmental change in haptic perception can be attributed to change in children's exploratory behavior. A third hypothesis Munsinger & Kessen, 1966) was that developmental change in form perception and exploratory behavior is related to the complexity of the forms used.

To test these hypotheses 144 kindergarten, second- and fifth-grade children were given targets successively in pairs to explore visually or haptically, and asked to tell whether each comparison target was the same as or different from the preceding standard. Twelve children at each grade level were assigned to each of four conditions corresponding to the perceptual systems to which the targets were presented: visual-visual, visual-haptic, haptic-visual, and haptic-haptic.

The visual targets were projected slides of irregular, black, planometric forms differing in perimeter and ranging from 5 to 48

angles in contour. Haptic targets, identical to the visual ones, were cut out of ¼ inch masonite and mounted on plywood fields. On haptic trials on opaque shield was used to occlude the targets from view. Exploration time for the targets was not limited; the inter-target interval was 7 seconds. Sixteen same pairs and sixteen different pairs of targets were presented to each subject.

The children's identifications of targets as the same or different and the time they spent exploring them was recorded. Haptic exploratory behavior was recorded on video-tape.

The children's correct responses were analyzed as a function of Grade (age), presentation condition, type of pair (same or different), and target complexity, by analysis of variance. In general, children at all grade levels in all conditions performed better than chance. Correct responses were made more often when standard targets were explored visually than when they were explored haptically and when comparisons were explored with the same perceptual system as the standard than when they were not.

In general, correct identifications increased with age in all conditions although more in the haptic-haptic and visual-haptic than in the visual-visual and haptic-visual conditions. The rates of change with age in the inter-system conditions were dissimilar and change in neither condition can be attributed to change in visual or haptic perception alone. Complexity effects on correct responses were negligible: high complexity targets were correctly identified only slightly less often than low complexity targets and this effect was unrelated to age.

Several aspects of the children's exploratory behavior, especially as they could be identified in the video-tape records of their haptic exploration, were quantified and analyzed in an attempt to relate variation in exploration to variation in correct identification of targets. Age-related differences in exploration on correct, as compared to incorrect, response trials were also analyzed. In general, it was found that older children explore more thoroughly than younger children, especially on forms of higher complexity. Exploration on correct trials was found to be different from exploration on incorrect trials but only for older and not for younter children. Since exploration differences were related to response accuracy for fifth-graders but not kindergarteners it appears that variation in some factor other than exploration influences the accuracy with which kindergarteners identify targets.

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A DEVELOPMENTAL STUDY OF VISUAL AND HAPTIC PERCEPTION OF FORM

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DEDICATION

This thesis is dedicated to the memory of my grandfather Duncan A. McRae.

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Research in the psychology of perception has long been directed toward the description of the capacities and an understanding of the development of capacities of the various perceptual systems in man and other animals. Within recent years there has been a burgeoning of interest in the development of perceptual skills that require use of more than just a single perceptual system. The terms used to describe this kind of perception have varied.

Most commonly, perception in which more than one perceptual system is involved has been called "cross-modal", "inter-modal", or "inter-sensory" perception where the perceptual systems are thought of as sense modalities. Adherents of this view conceive of perception as grounded in the sense data deriving from the sensory modalities that the target is stimulating.

Less commonly, perception involving more than one perceptual system has been called "amodal" perception (Gibson, 1969) where the perceptual systems are thought to be modes of external attention to information in stimulation. James Gibson (1966) conceives of perception as the detection of information specifying targets in the organism's environment and, when this information can be detected by more than a single perceptual system, amodal perception is possible.

In the pages to follow, these two views of perception, as they pertain to perception in more than one perceptual system, and the research relating to each, will be discussed.

THE SENSATION-BASED THEORY OF INTER-MODAL PERCEPTION OF FORM

The sensation-based theory of perception has seen variation and elaboration since its origins in the writings of the British Empiricists. Current major proponents of the theory include Hebb (1949), Vernon (1954), and Bruner (1957). Since their views vary slightly from one another it is hard to attribute the general theory described here to any single person.

Although vision has been the focus of most of the interest in perception, theories of perception and perceptual learning have evolved to explain perception in other modalities as well. Inter-modal perception is merely a special case to which these general theories have been applied.

Psychologists have long recognized that any target is complex in terms of the dimensions along which variation can take place over time. The "same" target can assume many different forms, colors, and textures, and the relations among these elements can vary widely. Furthermore, the orientation of the target relative to the receptor (the retina or the hand) can change over time. Clearly, the pattern of energy at the receptor (the impingement) aroused by the target at any moment in time is a unique event that, in all liklihood, will never be duplicated. The problem facing the psychologist is to explain the fact that many unique impingements can lead to a "common" response; this seeming paradox has been called the "constancy" problem in the research literature.

The traditional sensation-based theory of perceptual learning holds that the organism must somehow take all of these unique sensory

experiences and combine them, or "categorize" them, as Bruner (1957) has put it, so as to be able to attach the "same" response to the group. Thus, a single class of stimuli can be associated with some response (class), and learning can be observed. This kind of stimulus classification includes what has been called "stimulus generalization" (both primary and secondary) and "acquired equivalence of cues", and both phenomena have been demonstrated in numerous studies.

The sensation-based theory of perception as specifically applied to inter-modal perception dates back to Sherrington (1906), who suggested that, while man does not have a greater number of sensory channels and while his senses are not necessarily more sensitive than other animals', man does possess more adequate "linkages" between his sensory channels. The significance of this difference lies in the adaptive advantage given an organism having a greater capacity to perceive a threat to his well-being when the threat can be perceived by more than one rather than just a single modality.

Inter-modal perception is possible, of course, only with targets that can be sensed by more than one modality. For example, color can be "sensed" only visually; form can be sensed either visually or tactually and therefore is a target dimension that has been studied in visual and tactual inter-modal perception. Before discussing research pertaining to visual and tactual inter-modal perception of form the theoretical basis for this research will be discussed.

Although the sensation-based theory of perceptual learning has been applied explicitly only to intra-modal perceptual learning, its applicability to inter-modal learning is obvious. In intra-modal perceptual learning a person comes to realize that an object having a concentrically radiating texture or brightness gradient and a round appearance is three dimensional and is called a sphere. Thus, over time and experience with spheres he comes to associate those visual cues with the three-dimensional quality of sphericity. Inter-modal learning takes place when he looks at and feels a sphere at the same time. Under such circumstances of contiguous visual and haptic sensations, these sensations become associated with each other. In the future the feel of an object will arouse sensations similar to past haptic sensations which in turn had been associated with particular visual sensations aroused by a particular object that had been looked at. Feeling an object thus can give some "idea" of the visual appearance of the object: one should be able to identify an object in a visual array that is the same as another object that is simultaneously being felt but not seen.

Hebb's (1949) view of perceptual learning is in many ways similar to this traditional sensation-based theory, but because of its importance among theories of perceptual learning it deserves special mention. According to Hebb, when an organism first encounters a target the energy at the receptor field (impingement) is conveyed to the brain where that particular impingement is somehow recorded. Subsequent experiences with the target will produce impingements in some ways identical to, and in other ways different from, previous impingements, and the "record" will reflect this partial overlap. Brain cells that are aroused consistently whenever a target is presented becomes "linked" in what Hebb calls a "cell assembly". Once an assembly has been "laid down" it subsequently can be aroused in its entirety when only part of the assembly is stimulated. The development of such a mechanism would facilitate recognition of targets because the organism need detect only a small part of the total information (impingement configuration) inherent in a target to respond appropriately. Errors in recognition also become possible because different targets can have elements in common so that a new target may not be distinguished from an old one for which an assembly has already been established. This model best describes perception with the eye, but it also can be seen to describe perception with the hand and, to a lesser extent, perception with other modalities.

Perceptual learning, then, consists of laying down of cell assemblies, and, extending this notion, inter-modal perceptual learning would consist of the laying down of assemblies that are aroused simultaneously by impingements deriving from different modalities. Such an extension of Hebb's model to inter-modal perceptual learning would require the assumption that cell assemblies, though deriving from different modalities, <u>can</u> have cells in common given certain circumstances of arousal. Once links between assemblies relating to different modalities have been established, stimulation deriving from only a single modality, touch, for example, would cause the entire assembly, including its visually laid-down parts, to be aroused.

Given a sensation-based theory such as Hebb's, it is clear that inter-modal and intra-modal perception should require different experiences for their development: the contiguity of sensation from vision and touch is <u>essential</u> for the formation of an inter-modal assembly; inter-modal perception should be impossible so long as the perception of a target in the different modalities takes place successivly. Evidence that inter-modal and intra-modal processes are distinct might be obtained in either of two ways: In one, normal development might be simulated in a training experiment; in the other, children of different ages would be tested in visual and haptic intra-modal and inter-modal tasks and inferences drawn from performance differences among the different tasks to the process or processes underlying those differences.

In a training experiment subjects would be trained to discriminate among novel (unfamiliar) forms which they can only touch, only look at, or simultaneously look at and touch. Subjects in this latter condition in this way presumably receive practice associating visual and tactual cues deriving from the same form. Subsequent transfer tests could then be given in which visual and tactual input, though simultaneous, are kept separate. (Subjects would not be able to see the form they are feeling but, instead, could see a form that is <u>like</u> the form they are feeling.) Only those subjects receiving training in which bimodal input was associated should be able to transfer this training to the test condition.

The most important consideration in this experiment is that the forms be unlike anything the subject has experienced before. If such forms could be devised, no age differences relating to the forms would be expected, as they should be equally unfamiliar to subjects of different ages. In practice, the criterion of complete novelty is impossible to meet, since any form will be similar in <u>some</u> way to a form with which a subject has had prior experience. Therefore, the relative novelty of a form might be expected to decrease as the subject's age, and therefore his experience, increases.

Transfer between vision and touch, without explicit training in the context of the experiment, would be expected to vary as a function of the novelty of the objects used relative to other objects with which the subject has had prior experience associating input to the two modalities. Age differences should be found here too just as in conditions of intra-modal presentation.

Despite the inevitable confounding of novelty effects with training effects in any age differences observed, a bimodal training study would be valuable insofar as it could be presumed to model the natural conditions for inter-modal perceptual learning. Such a study has never been conducted. If the study were developmental, it would have the further value of identifying the lower limits of training effectiveness. Birch and Lefford (1963) hypothesize that the development of inter-modal functioning found in their research (to be discussed later) reflects neurological change in the "linkages" between the senses. Only a training study that does not succeed with youngest subjects can lend support to neurological and not to experiential interpretations. Obviously failure to train young children can be due to many factors including the one hypothesized by Birch and Lefford, so any such failures would not constitute very strong support for the hypothesis.

In the absence of evidence to the contrary, it is as reasonable to postulate an experiential basis for behavior change as it is reasonable to postulate a neurological basis, and it should be pointed out that Birch and Lefford's evidence is entirely behavioral and not histological.

Finally, negative results in and of themselves are of questionable value, but their value increases significantly in certain contexts.

The value of training studies would be enhanced by supportive findings from "controlled observation" of the natural development of inter-modal processes.

All past research on inter-modal perception has been designed to measure the natural development of the capacity. In terms of a traditional view of perceptual learning one would expect a positive relation between intra-modal competence in perception (recognition or identification) of common objects and the subjects' age because of the increased experience with those objects that is presumed to take place over time. For the same reason, intermodal perception ought to improve with age. While inter-modal and intra-modal perception of common objects require distinct sorts of experiences for their development, strictly speaking it is impossible to tell to what extent these experiences are distinct as they naturally occur. Perhaps exclusively intra-modal experience with most forms occurs only rarely and, in the usual course of events, any target is apprehended with more than one modality. If such is the case, inter-modal and intra-modal perception, though relying on distinct experiences, may show overlapping and hence indistinguishable courses of development. On the other hand, if inter-modal perceptual development were not found to parallel perceptual development of either modality taken separately, one could justifiably conclude that distinct processes are involved in the two types of perceptual learning.

Research on inter-modal perception has been oriented implicitly, if not explicitly, toward this traditional view of perceptual learning. But before considering that research, Gibson's view of perceptual learning will be described, although it has stimulated but a single study,

because this view is so different from a sensation-based theory and is of such potential importance for understanding inter-modal phenomena.

THE GIBSONIAN THEORY OF TRANS-SYSTEM PERCEPTION OF FORM

Though Gibson (1966) acknowledges that no two impingements are ever exactly alike, he does not accept the view that one's perceptual-cognitive apparatus somehow puts impingements together, fitting them into categories. Instead, he suggests that there are invariant properties (critical features) of objects which organisms learn to detect. Objects are identified by an organism despite variation in impingements because the information defining the form for the organism is present in each impingement. "Constancy" for Gibson has nothing to do with impingements somehow being put together; rather it means that there is constancy of information over successive impingements.

Similarly, perception of an event by means of more than one perceptual system[1] does not involve "associating" or "putting together"

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[1]James Gibson proposes that "perceptual system" and not modalities are more reasonable units and he seems completely correct in this. Under the traditional view, the visual modality refers to retinal and other processes neurologically related to those receptor cells. Although the muscles that control the eye are very much a part of visual perception and have been thought to play an important role in illusions and depth perception, for example, they are not included in what is properly called the visual modality. Similarly the tactual modality has not included proprioceptive and kinesthetic cues although all three occur, inextricably linked together, in most tasks in tactual perception. Gibson has recognized this confusion over what is meant when one refers to a visual or a tactual perceptual task and has proposed that the term 'system' be used to include all the different kinds of information from the various receptors that are used in a visual or haptic perceptual task.

The term "modality" rather than "system" has been used thus far in the description of the sensation-based theory because that is the term used by these theorists. Probably they intended to mean what Gibson means with "system". Because Gibson's term is so much more reasonable it will be used in the remainder of this paper.

the information deriving from each. Rather, the organism detects information with both systems, with each "kind" of information specifying the same thing. In other words, information does not have to be associated because the target does not vary; the only change is in the perceptual system by which the information is detected. As was mentioned earlier, Eleanor Gibson (1969) has called information that is not specific to a perceptual system "amodal". This term will not be used here.[2] Instead, information relevant for more than one system will be called "trans-system" information. Texture density and the relations among the sides of an irregular shape are two aspects of targets that might be distinctive critical features and relevant for both touch and vision and hence could be called trans-system information.

Trans-system information constitutes a subset of all the information that can be detected with any perceptual system. The psychologists' job, so far as Gibson's theory is concerned, is to determine what kinds of perceptual invariants are detectable exclusively by a given system and what kinds are trans-systemic. Perceptual development, according to Gibson's view, amounts to learning to detect those features of events or things that distinguish them from other events or things. Children, therefore, should become better in perceptual tasks as they grow older because they should become increasingly able to detect these distinctive features.

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[2]The term "amodal" is misleading in two respects: first, amodal suggests the use of modalities and not systems in perceptual tasks when James Gibson has argued for the greater reasonableness of systems as information detecting units. Second, calling information 'amodal' suggests that it has no effect on a perceptual system. James Gibson has argued against the possibility of perception without sensation, which is what the term 'amodal' implies.

There should be similar improvement with age in trans-system as in single system tasks although performance in trans-system tasks may be lower. Performance should be lower in a trans-system task because there is less information relevant to more than one system than there is information relevant to any single system, and a direct relation ought to exist between the amount of relevant information and performance in a perceptual task.

Training studies would be relevant to Gibson's theory of perceptual development insofar as the training experience could be presumed to model "natural" experience. Eleanor Gibson (1969) suggests that a training study involving trans-system invariants need only consist of training in one perceptual system; learning to detect distinctive features in one system can subsequently facilitate detection in another system, since the features are common to both. Such a training study is an appropriate test of a prediction from this theory, but it seems to be an unnecessarily stringent test because it assumes equivalent capacity for detecting information in the different systems. So far as the theory is concerned, it is only necessary that the subject not be given an opportunity to "associate" information detected by the two systems. Thus, he might be given training in each of two systems separately and then asked to perform in a trans-system task. Such training should facilitate performance because his ability to detect information with each system, including trans-system information, should improve.

Unfamiliar objects must be used so that the child will have something to learn and also to minimize the role of past experience in which discriminating the objects could have been accomplished with both systems operating concurrently. The stimulus objects, of course, also must be detectable by either perceptual system.

Pick, Pick, and Thomas (1966) conducted a training study that bears on Gibson's theory, in which first grade children were taught to discriminate visually and haptically among certain types of letter-like forms and their transformations. In previous research (Gibson, Gibson, Pick, & Osser, 1962; Pick, 1965) the distinguishing features of these forms had been found to be detectable in both the visual and haptic perceptual systems. In the Pick, Pick, and Thomas study, initial training took place either in the visual or haptic system followed by re-training in the other system. The effects of training were measured by comparing performance in a system with and without prior training in the other system.

This was not a developmental study; its objective was to compare the effects of different characteristics of forms on transfer of training. There were several types of forms and several variations of each type. The different variations followed certain principles which were applied to each type so that the same variation was found across the several types of forms.

All children learned to discriminate among a particular set of letter-like forms containing certain types and certain transformations of each type. The forms used in the transfer task differed in three ways from those used in the initial discrimination task, and a different group of subjects was used with each. The first group was re-trained with the same types of forms but with different variations of each type of form. Transfer would be expected for children in this group if, in the initial learning trials, they had learned something about the basic type of form with which the different variations could be compared in a kind of match-mismatch fashion. A second group of children was retrained with different types of forms but forms that had been transformed in a similar way as the initial training forms. Transfer would be expected in this condition if the children had learned something about the critical features (dimensions of difference) among the forms. A third group of children was retrained with forms of a different type and transformed in a different way from the training forms. No transfer would be expected of this group except, perhaps, that of a general "learning-to-learn" variety not specific to the forms used.

The results showed transfer only in the first two groups though inconsistent transfer in the first. The Gibsonian predictions are most consistently supported by this study (the second group described above), but the associationist (Hebbian) position also receives some support (the first group described above); it is not known what factors produced the uncertain results in the latter case. This study is interesting nonetheless because it marks a first attempt to use forms that differ in a systematic way from each other and for which the relevance of the dimensions of difference for both perceptual systems has been demonstrated. Whether or not the transfer shown can be attributed to the trans-system nature of these dimensions of difference cannot be determined. Since this was not a developmental study and since intra-system comparison groups drawn from prior research had slightly different test conditions, it could be that transfer was possible because prior bi-system experience was relevant for these forms. In another experiment bi-system training might also be carried out to model what might be normal experience in perceptual development. Further research with forms like those designed by the Gibsons looks particularly promising.

Numerous studies have been conceived in the spirit of a sensation-based theory of perceptual development and in general have attempted to show that: 1) human subjects are capable of inter-system perception, 2) the capacity for inter-system perception improves with age and, 3) inter-system and intra-system perceptual development are distinct processes. Few of these studies have attempted to consider all three of these basic questions within a single design. Furthermore, because different methods have been used to study the same process, it is likely that the picture or characterization which each study gives us is colored to some degree by the method employed.

Each of these methods will be considered separately and the research using each presented and evaluated to determine to what extent these three questions have been answered. Finally, we will examine how each method treats the development of the perceptual-cognitive organization of visual and haptic information about form.

RESEARCH RELATING TO A SENSATION-BASED THEORY OF INTER-SYSTEM PERCEPTION

A. Research using a transfer-of-training method. Inter-system perception of form has been studied using a transfer-of-training method. With this method subjects are divided into two groups. Several forms are presented to one group for visual exploration and to the other for haptic exploration.[3] The forms are presented repeatedly until they

[3] To be strictly accurate, it is necessary to describe the operation of presenting the forms and not the subject's response (looking

can be discriminated to some criterion level of performance. The same forms are then presented to each group in the other perceptual system until the criterion level performance is again reached. The number of trials or errors to criterion might be used to show the rate of learning in each system. The effect of pre-test exposure to forms in the other system can be shown by comparing the results from both groups. For example, the visual performance of one group that has had prior experience in the haptic system can be compared with the visual performance of the other group that has had no prior experience with the forms.

An important drawback to this method is that learning experience _per se_ is confounded with transfer effects. Two additional control groups, shown different forms in each system, are needed to distinguish general learning experience from experience that is specific to those forms presented previously in the other perceptual system.

Finally, initial training in visual and haptic discrimination must be studied as a function of age in order to tell whether or not changes with age in inter-system discrimination occur independently of improvement in intra-system discriminations. Change in inter-system discriminations may be merely an artifact of improvement in intra-system discriminations.

Gaydos (1956) and Eastman (1967) used a transfer of training method to investigate inter-system perception of form with adult

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at them, say) because his response does not always correspond perfectly to the operation. Although it is important to distinguish between the activities of the experimenter and the subject it will be awkward to maintain this distinction throughout the discussion to follow. Therefore the distinction has been deliberately blurred in the text.

subjects. Gaydos paired verbal labels with amorphous shapes which she allowed one group of subjects to look at and another to feel. When the labels associated with the forms had been learned in one system the forms were presented in the other until the proper labels were again learned. Gaydos compared the relearning performance of one group with the initial learning performance of the other for both touch and vision. Transfer was demonstrated in both systems with greater transfer from touch to vision than from vision to touch.

Eastman used irregular randomly generated forms of 4, 8, and 16 sides for discriminanda but in other respects treated his subjects in the same way as did Gaydos. His transfer test, however, consisted of only one trial in the other perceptual system and his measure was the number of forms labeled correctly. Like Gaydos, Eastman found more transfer in the T-V than in the V-T condition. There was no form complexity effect: the number of correct judgements the subjects made did not vary as a function of the variation in the discriminanda.

Two similar studies have been conducted with children. Blank, Altman, and Bridger (1968) taught four-year-olds to discriminate between two block-like forms. The forms were presented simultaneously for visual or haptic exploration (the children could use both hands in the haptic condition) until the criterion level for discrimination was met. The two forms then were presented in the other perceptual system until the subjects were able to discriminate them. The results show transfer in the V-T but not in the T-V condition.

Pick, Pick, and Thomas (1966) presented several letter-like forms to first grade children (six-year-olds) for visual or haptic exploration. This study, which was discussed earlier in detail, was designed to answer a different question from the three main questions posed above and, as a consequence, the training methods used in the two transfer conditions were different. Their results show transfer of discrimination training in both the V-T and the T-V conditions in six-year-olds. The differences in training under the two conditions preclude evaluation of the relative efficiency of the transfer conditions.

To summarize, these studies show transfer of experience from vision to touch in subjects ranging from four-year-olds to college students. Transfer from touch to vision has also been found in subjects between six years and college age although not in four-year-olds. Finally, there is some suggestion that transfer is more efficient among college students from touch to vision than from vision to touch, which suggests that, although later to develop, transfer from touch to vision is greater.

These differences in the relative efficiency of transfer across subjects of different ages may or may not reflect important developmental change. Any conclusion must be tentative because these studies not only used subjects of different ages but they also differed in the forms used and in procedural details so that what appear to be age differences in transfer may only be differences in procedure. It is also unclear whether the observed age differences in transfer reflect inter-system or intra-system perceptual development and finally, whether these differences might merely reflect improvement with age in "learning to learn".

Only the study by Pick, Pick, and Thomas used control groups to ensure that what was transferred was information specific to the forms and not merely general task experience. Although their results show no non-specific transfer effects, it would be premature to assume that such effects may not operate in other settings with subjects of different ages and with different forms to be discriminated.

Any conclusion about the development of inter-system transfer with age from research using this method must await a study in which the same forms and procedures are applied to subjects of different ages in both an inter-system and an intra-system transfer task.

B. Research using a simultaneous match-to-sample method. A simultaneous match-to-sample method (often called the "conflict" method) has been used to study inter-system equivalence of form perception. With this method forms are presented to the two perceptual systems simultaneously: a single form (the standard) is presented in one system, and several forms (the comparisons) are presented in the other. The subject is asked to pick from the comparisons the form that is the same as the standard. A correct choice presumably reflects equivalence between the two perceptual systems.

Two important points should be made about this method. First, the relatively greater efficiency of visual relative to haptic exploration makes haptic and visual identification of a standard among several comparisons very different tasks. Results, therefore, are likely to depend on the system of presentation, so counterbalancing is necessary. Counterbalancing is required only so long as several comparison forms are used; the problem is avoided when only one form is presented to each perceptual system.

Second, this method, though commonly used, does not really permit conclusions about the development of inter-system equivalence.

Improved performance with age may mean improvement in equivalence <u>or</u> improvement within a perceptual system. Two intra-system groups (V-V and T-T) are also needed (the haptic condition would require that the subject use both hands) so that inter-system and intra-system changes in performance can be distinguished from each other.

The simultaneous match-to-sample method has not been used to study inter-system perception in adults, though there have been several studies with children. Rudel and Teuber (1964) presented three-dimensional geometric shapes to two groups (V-V and T-V) of three-year-old children. Children in the V-V condition made more correct judgements than children in the T-V condition (3.3 vs. 2.3). These findings are suggestive at best: no statistical analyses were reported, and the means for the two groups were based on the performance of three children per group each of whom made only five judgements.

Lavrent'eva and Ruzskaia (1960) presented Gaydos' forms to three-, four-, five-, and six-year-old children. Two forms were presented in one perceptual system while a third was presented in the other. The subjects were asked to indicate which one of the two comparison forms was the same as the standard. Both a V-T and a T-V condition were used.

The data were presented as percent errors but, with no further analysis and no mention of the number of subjects involved, the reliability of differences between conditions at different age levels is hard to assess. In general, the data suggest that there was no improvement in discrimination from a chance level in either condition between the ages of three and four. Subjects in the T-V condition showed a marked improvement from 50% (chance) to 25% errors between four and five years of age. There was no further improvement between five and six. However, subjects in the V-T condition performed no better than chance through five years of age. Then, between five and six, their performance improved markedly from chance to near-perfect level. The results suggest earlier improvement in the T-V condition, and later improvement and ultimately superior performance in the V-T condition.

Birch and Lefford (1963) studied inter-system equivalence between vision and touch in five- to eleven-year-old children. They used forms from the Sequin form board test; the children looked at a single form while feeling several others in succession. Nine comparison forms corresponded to each standard form with two of the nine being the same as the standard. The children were asked whether the comparison and the standard were the same or different. Consistent with Lavrent'eva and Ruzskaia, the older children made fewer errors than did younger children.

Birch and Lefford's study is flawed in several important ways, however; first, they used only a V-T condition and did not counterbalance with respect to the perceptual system in which comparison forms were presented (a particularly significant oversight, since it was their aim to show the development of transfer between different pairs of perceptual systems). Thus, they cannot tell whether developmental differences between conditions are due to differences between the pairs of systems or to differences with respect to the particular system in which the comparisons or standards were presented.

Second, the error rate was found to vary as a function of the judgement required: more errors were made when two forms were the same than when they were different and a minimum error rate was reached by eight years of age for "same" pairs while errors for different pairs continued to drop after eight years. These findings might mean that different perceptual processes are involved in same and different judgements. Birch and Lefford did not present an equal number of "same" and "different" pairs of forms, so the children's responses of "same" and "different" were not equally likely events and as a consequence, a response bias may have been induced. Therefore, the different rates of improvement for "same" and "different" pairs may reflect a perceptual-process difference or merely a methodological bias; a proper interpretation cannot be made.

Finally, Birch and Lefford presented the same standard and comparison forms in the same order to all children in a visual-kinesthetic condition before presenting them again in the visual-haptic condition. While the first condition is not of interest here, it is likely that this prior experience influenced the results in the visual-haptic condition, particularly in view of the partial identity of information deriving from haptic and kinesthetic exploration. Without counterbalancing the order of the two conditions it is impossible to tell what effects, if any, prior kinesthetic experience with the forms had on the subsequent haptic condition. Thus, experience effects as a function of age were confounded with changes in inter-system equivalence as a function of age. In view of the significant methodological ambiguities in this study, no conclusion appears warranted regarding the development of transfer between vision and touch.

A study by Blank and Bridger (1964) has also used the simultaneous match-to-sample method. Three-, four-, and five-year-old children were given pairs of common forms (cylinder, triangle) to look at while feeling one behind their backs. The children were asked to point to the one form they were shown that was the same as the one they were simultaneously feeling. Blank and Bridger did not counterbalance for the system in which comparisons were presented. Consistent with Lavrent'eva and Ruzskaia, four- and five-year-olds but not three-year-olds were able to identify the form.

It is clear from Lavrent'eva and Ruzskaia's findings that equivalence is in part a function of the perceptual system in which the comparison forms are presented. Thus Blank and Bridger have only partly described the changes in inter-system equivalence between the ages of three and five. Finally, in view of the absence of intra-system comparison groups in these studies using the simultaneous match-to-sample method, research with this method has not convincingly shown that inter-system and not intra-system processes are involved in the developmental changes observed.

C. Research using a successive match-to-sample method. This method is the same as the one just described except that a memory component is involved, since forms are presented to the two perceptual systems successively rather than simultaneously. Typically, a single form (the standard) is presented in one perceptual system followed by several forms (the comparisons) in the other. As with the simultaneous method, groups that are counterbalanced with respect to system of presentation (V-T and T-V) are needed. Intra-system comparison groups (T-T and V-V)) are also required with this method.

This method has been used to study inter-system perception in two experiments with adults. Vaught (1968) used Gaydos' forms in a haptic exploration, visual comparison (T-V) task. (The number of forms and their manner of presentation are not described in his report). The subjects identified the form they had felt among the several they looked at significantly better than chance indicating that there was transfer from touch to vision. The appropriate controls were lacking however: there was no V-T group, nor were there intra-system groups.

Cashdan (1968) also used Gaydos' forms but had his adult subjects explore the forms through a hole in an opaque board thereby forcing exploration of successive parts of the form. In this way visual and haptic exploration were made similar. Following explorations of each standard, five comparison forms were presented in succession and the subjects were instructed to identify the standard among the comparisons. Four conditions were used, two inter-system (V-T, T-V) and two intra-system (V-V, T-T). Each subject had two trials in each of the four conditions.

This study is unique in that subjects' exploration was controlled. Unfortunately, the order of treatment conditions apparently was not varied across subjects, and the inter-system treatment conditions were confounded with forms (all subjects in a treatment condition saw the same forms and different forms were used in each treatment condition). Apparently realizing that factors were confounded, Cashdan replicated the first study with new forms assigned to each treatment (and still confounded). Since the assignment of forms made a difference, the only consistent findings were that the intra-system conditions (V-V and T-T) were easiest and most difficult respectively. The inter-system groups were of intermediate difficulty.

The successive presentation method also has been used to study inter-system perception in children. Lobb (1965), using random shapes, presented five standards each followed by an array of four comparisons consisting of the standard and three other forms. The subjects, eighth-grade children, were assigned to two inter-system and two intra-system groups. Each child received five trials with each standard. In general, presenting the standards visually led to better performance than presenting them haptically. Differences between the groups were evident only on the first and not on later trials: especially on early trials, performance was depressed by having the subjects switch to the haptic system to identify comparisons when standards had been presented visually. Finally, there was some evidence on early trials that the V-T group performed better than did the T-V group.

Rudel and Teuber (1963) presented three-dimensional forms to four- and five-year-old children. Five comparisons were presented in succession following each of five standards. In general, children in the V-V condition made the most correct judgements, and children in the T-T condition made the least, with children in the inter-system (V-T and T-V) conditions performing in between; five-year-olds tended to make more correct judgements than four-year-olds. These results are only suggestive, however. The data were not analyzed; only group means were presented; each mean was based on the performance of only three children each of whom got but five trials, and the differences between means were small.

Hermelin and O'Connor (1961) presented 10 pairs of letter-like forms, members of each pair shown successively, to four groups (two inter-system and two intra-system) of five-year-old children. The children were asked whether the two forms of a pair were the same or different. The analysis showed no differences between the groups, but the authors do not report whether performance was better than chance although it might be assumed that it was.

Researchers in the Soviet Union have studied inter-system perception of form among children between the ages of three and seven. Lavrent'eva and Ruzskaia (1960) tested two groups of children (the number per group was not mentioned) at each age level, one age group in each of the two inter-system conditions. Each child was given Gaydos' forms one at a time to either look at or feel. Following exploration of each standard the children were asked to identify it in an array of three comparison forms presented in the other system. The results indicated greater T-V transfer than V-T transfer among three-, four-, and five-year-olds. By six years of age, however, there was no difference between T-V and V-T groups.

The report makes no mention of intra-system control groups. However, a reference to this experiment in Pick's (1964) review of Soviet research in perception includes a table giving summary scores for two intra-system groups of subjects as well as for the two inter-system groups named above. The results for these two intra-system conditions show fewest errors in the visual system and most errors in the tactual system, relative both to each other and to the inter-system conditions. Improvement was marked in the visual system as a function of age:

errors dropped from 50% at age three to zero at age five. Errors also dropped in the haptic system, from 70% at age three to 40% at age six.

The reliability of these results is hard to assess. Typically, the Soviet researchers report only percentages, give no indication of the variability of subjects within groups, and report no statistical tests. Pick (1964) regards the results as suggestive at best.

In general, it does not appear that any of the research thus far conducted with any of the methods has been both properly designed and properly executed so as to permit inter-system and intra-system perceptual development to be distinguished from each other. Bryant (1968), in a review of a subset of studies reviewed here reaches this same conclusion. The greatest need in all of this research is for a study of inter-system perception of form in children between the ages of three and eleven having appropriate intra-system controls.

Even with adequate control groups and data analysis, the extant studies would remain inconclusive because the manner of use of the three basic methods of analysis often has allowed the developing process under study to be obscured by other psychological processes that are developing concurrently. One particularly important instance of this confounding is the extent to which these studies have relied on the subject's memory. Both the successive match-to-sample method and the transfer-of-training method require the subject to remember something about the form or forms to which he was initially exposed. While memory for form within or between perceptual systems has not been studied developmentally, it seems likely that changes in this capacity would take place between the ages of three and seven. Therefore, it

seems unwise to study perceptual development in such a way that memory factors are inextricable from the perceptual process of interest. Support for this methodological point can be found in the study by Rudel and Teuber (1964), who report that their three- and four-year-old subjects were unable to perform on either the within- or between- perceptual systems-tasks when forms were presented successively. These same children could perform when the forms were presented simultaneously. Since an important difference between successive and simultaneous discrimination tasks is the memory required of a subject, the observed performance differences between children in the two tasks may be attributable to an insufficient memory capacity. It must be mentioned, though, that Rudel and Teuber not only presented standard and comparison forms successively; they also presented multiple comparisons among which the standard was to be identified.

The presentation of multiple comparisons, especially in succession, may confuse children of different ages in different ways. For example, Rudel and Teuber (1964) asked the children to identify "the one" that was the same as the standard. If a child understood those instructions and decided that the first or the second comparison form was "it", what must he have thought when the experimenter said nothing, proceeded to the next comparison form, and asked whether that one was "it"?

Age-related confusion when many comparisons are successively presented might arise in another way: while the child tries to remember the standard form as each comparison is presented, he must also try to not confuse memories of incorrect comparisons with his memory of the standard as other comparisons are subsequently presented. In

other words, when a subject views the fifth comparison in a series, it should be more difficult for him to remember the standard that preceded the series because of interference from memories of the first comparisons. There is no reason to assume that such confusion will not arise in different degrees with children of different ages. Again, these features of the procedure make it difficult if not impossible to separate change in the process under study from change in subjects' responses to some aspect of the measurement of that process. All but one of the studies reported above, using a successive match-to-sample-method, used multiple comparisons following a single prior presentation of the standard.

Some of the studies also imposed time limits on exploration, thus preventing free exploration of the forms. The use of time limits could be appropriate in a study of the efficiency of exploration, but would be clearly inappropriate when the aim is to assess the child's capability to perform. The use of time limits also would suppress individual differences between subjects of the same age and could conceal differences in the efficiency of exploratory behavior. Since the effects of a time limit are likely to be related to the subjects' age, the results would tend to show age change in behavior as dichotomous when it might be continuous.

While we probably can conclude that inter-system perception is possible in children as young as four or five years of age, the extant studies have not satisfactorily plotted the growth of the capacity for inter-system perception, and they have not shown that inter-system and intra-system perceptual learning are distinct processes. Finally, while we know that children can make inter-system judgements at age four, we do not know whether their inability to make such judgements before that time reflects lack of experience or some state of neurological immaturity.

FORM AS AN INDEPENDENT VARIABLE IN PERCEPTION RESEARCH

Virtually all research on inter-system perception has been concerned with the <u>fact</u> of inter-system perception rather than with the nature of the discriminanda involved. In other words, most investigators have attempted to assess the information-organizing capacity of cognitive-perceptual systems while neglecting to ask what is being organized. Only Eastman (1967) and Pick, Pick, and Thomas (1966) (reviewed earlier) have attempted to measure the relation between specific properties of forms and inter-system perception and only the Pick et al. study showed any relation between form properties and performance. This lack of interest in the role of form parameters in inter-system perception probably reflects the lack of an adequate metric for form for either vision or touch. Indeed, as recently as 1968, Brown and Owen suggested that attempts to define a metric for form lead to "methodological dyspepsia". From their and others' work it seems to be impossible to design forms that differ on only a few dimensions (that can be simultaneously controlled) while not differing unsystematically on other dimensions at the same time.

Even though a form cannot be completely specified, numerous studies of visual perception of random shapes have been carried out, and some interesting relations have been demonstrated between certain form variables and certain psychological variables. In particular, Munsinger, Kessen, and Kessen (1964) have shown that stated preference for random shapes varies as a function of the "complexity" of the shapes (although now it seems that the critical variable was in fact the perimeter of the forms). Looking time has also been found to vary as a function of form complexity or perimeter (Johnson, 1968). Since the information contained in a form is a direct function of its complexity it seemed reasonable to these researchers, and to others as well, that more "processing" would be required for a subject to learn to recognize a complex shape than a simple one. More complex shapes should also be harder to remember because of the greater information load they impose on memory. Munsinger and Kessen (1964) and Munsinger, Kessen, and Kessen (1964) hypothesized that stated preference for random shapes would accord with the information processing ability of subjects (which should vary as a function of age) and the available information in each form to be processed. They found an age-invariant preference for forms of about 10 sides and differences between five-year-olds, ten-year-olds, and college students in their preferences for complex shapes. In general, the older the subjects the <u>less</u> preference shown for the most complex shapes. Munsinger and Kessen suggest that this relation reflects changing information-processing ability with a concomitant change in exploratory behavior. They suggest that young children explore only parts of forms, consequently process about the same amount of information from both simple and complex forms, and therefore prefer them about equally. Adults, however, explore the forms in their totality and, finding the more complex forms harder to process, prefer them less than simpler forms. This work is pertinant to the analysis of inter-system perception because it suggests that a subject's ability to process information about form should vary as a function of his age and/or experience with random shapes and the information content, or complexity, of the forms to be processed in the task. It also implies a direct relation between the subject's ability to process information and his exploratory behavior. This relation deserved further discussion.

EXPLORATORY BEHAVIOR AND PERCEPTUAL-COGNITIVE DEVELOPMENT

Two views of perceptual-cognitive development emphasize the relation between exploratory behavior and knowledge of the object explored. On the one hand, Piaget and Inhelder (1956) suggest that the child's perceptual activity is essential to his cognitive development:

> ...the evolution of spatial relations proceeds at two different levels. It is a process which takes place at the perceptual level and at the level of thought or imagination. (p. 3)

Perceptual activity results in a child's developing a "scheme" which is a kind of cognitive representation of an object-as-explored. In other words, the representation of an object, a child's knowledge of it, is a function of the child's perceptual activity. It reflects the information _detected_ by the perceiving organism and is not a _copy_ of the object as it exists independent of the organism.

Representation of an object thus has a figurative aspect. Piaget and Inhelder (1956) emphasize that it also has an operative aspect in that the representation (scheme) is an organizing structure

for external acts: "... during the development of representational space, representational activity is, in a manner of speaking, reflected or projected back on to perceptual activity." (p. 4).

On the other hand, Leont'eva's theory of perception (Pick, 1964) holds that kinesthetic feedback from motor acts (reafference) constitutes the basis for perception. Exploratory behavior thus produces a copy of the physical object. Thus, for both Piaget and Inhelder and Leont'eva there is some correspondence between perceptual activity and what the organism knows about an object although the closeness of that correspondence differs for the two views.

Piaget's description of perceptual-cognitive development also can be seen to parallel Hebb's. Piaget's prototypical child, through systematic and thorough exploration, "puts the form together" in his representational system; Hebb's child forms cell assemblies. The similarity does not end here: Piaget has found that young children, while they explore erratically and make mistakes identifying geometric shapes, are very good at identifying familiar objects in spite of incomplete exploration of them. Older children also explore only parts of familiar forms and are also good at identifying them. It is as if the form has already been "put together" in their representational systems such that detecting any part of the composite can in a sense elicit or activate knowledge of the whole. Hebb has ascribed the same sort of economy to the arousal of cell assemblies once they have been established. It seems, therefore, that complete exploration of a form is required for the establishment of its representation, but, once it has been represented, only partial exploration is necessary for its identification.

Although James and Eleanor Gibson (1966, 1969, respectively) do not consider representation to play a part in perception, they do recognize the importance of perceptual activity in perception. According to their view, organisms actively seek information, invariant over time, that specifies objects (distinctive features) in their environment. Perceptual development involves improvement in the ability to extract information, or, to paraphrase E. Gibson, increased economy of information pickup.

Facts about visual and haptic exploratory behavior are scarce but suggest that age changes in exploratory behavior parallel changes in other measures of psychological development. Munsinger and Kessen (1964) suggested that young children look at parts of forms while older children and adults, though they may look at parts, put them together to form wholes. They subsequently attempted to show that if children look just at parts and not wholes, they will make more mistakes in a form identification-discrimination task than will adults who can grasp wholes (Munsinger & Kessen, 1966). In general, this was what they found though other interpretations are possible.

More recently, Vurpillot (1968) has shown, by directly recording eye movements, that children under five years of age tend to explore complex figures only partially while older children explore them in detail before making judgements about them. She found a close relation between the completeness of a child's exploratory behavior and the accuracy with which he could tell whether two complex pictures were the same or different. Vurpillot's work is clearly the best to date on the relation between visual exploration and visual discrimination.

Zinchenko and Ruzskaia (1960a, b) have also linked children's visual exploratory behavior with accuracy of form discrimination. They used Gaydos' amorphous shapes and recorded eye movements with a camera positioned at the center of the form. They found that three- and four-year-olds tend to look at the center area of the forms much of the time while children five years and older tend to follow the edge of the form with their eyes. Older children could discriminate better than younger ones presumably because their exploratory behavior was more thorough. Since information about the shape of a form is located at its boundaries, older children should be getting more information about the shape than younger ones. This research would be more convincing, however, had the camera not been placed at the center for the forms; the sample record of eye movements that Zinchenko and Ruzskaia present shows that the younger children who looked at the center of the form looked mostly at the lens of the camera. Therefore the age related differences in exploration and discrimination accuracy may have merely reflected the younger children's greater interest in the camera.

Soviet research on haptic perception indicates similar age-related changes in exploratory behavior and accuracy of discrimination, though haptic discrimination develops later. Piaget and Inhelder (1956) also related haptic discrimination to exploratory behavior in a way similar to the Soviets. In experiments with two- to seven-year-old children they report that, until five years of age, children explore unfamiliar geometric shapes haphazardly, centering on only some part of each shape before making a judgement. Older children explore

in much greater detail, and, presumably, their identifications of haptically explored forms consequently are more accurate.

Piaget's geometric shapes and the amorphous shapes used by the Soviets were unfamiliar to the subjects. Older children explored them in detail as would be expected when the forms have not yet been schematized, but the younger children explored them only in part which should prevent them from adequately representing the forms. Yet Piaget's finding that young children can identify familiar things indicates that such children are capable of representing forms. It appears that they can "put the forms together" though it might take much longer to do so. Presumably if they had had several opportunities to explore the geometric shapes they would have been able to identify them too though still exploring them only partly. The suggestion here is that, while both four- and seven-year-old children are capable of representation, they form the representation in greatly different ways.

One interpretation of these research findings is that children of different ages differ in the strategies they use to discover distinctive features of forms. Older children might explore all features of unfamiliar forms so as to detect all their potentially distinctive features. They need explore only parts of familiar forms because the features that distinguish those forms for the child are only a subset of all features that comprise them.

Young children, perhaps, explore only some of the features of unfamiliar forms thereby detecting fewer distinguishing features. They can identify familiar forms so long as they can find their distinguishing features.

Another interpretation of these research findings is that children of all ages will try to explore all aspects of a form to be able to identify it subsequently but that how much they explore will vary as a function of their ability to organize the information they are obtaining and the amount of information to be gotten from the form. The forms used in research thus far have been very simple but apparently contain too much information for young children to organize. Consequently, young children explore only part of them. Older children are able to organize the information in simple forms so they explore them completely. The implication, however, is that more complex forms might exceed older children's organizing capacity, so exploration of such forms would be incomplete.

It therefore would be particularly interesting to present very simple and very complex forms to children of different ages to see whether older children explore the simple forms completely, the complex forms only partly.

The current research represents an attempt to relate developmental change in exploratory behavior to developmental change in inter-system and intra-system perception of form in vision and touch. Clearly past research has not satisfactorily resolved questions concerning inter-system as distinct from intra-system development. It has also regarded inter-system perception as a strictly perceptual and not a perceptual-cognitive capacity relating in some way to the information aspects of the forms themselves. Finally, it has not considered exploratory behavior as a function of the subject's ability to organize information and the information in the forms to be organized. Consequently, exploration of form has not been studied beyond six years of age in spite of other evidence that cognitive development continues well beyond that time.

The current study is a developmental analysis of intra-system and inter-system perception of form in vision and touch in children between the ages of five and eleven. Four groups of children at each age level were tested to permit a distinction between inter-system and intra-system processes. Forms of various complexities were used to permit assessment of the relation between information complexity, correct judgements, and exploratory behavior. Haptic exploratory behavior was recorded and related to children's correct judgements, form complexity, and whether forms, taken in pairs, were the same or different.

METHOD

A. Subjects. The subjects were 144 kindergarten, second grade, and fifth grade children, 48 at each level, attending Dimondale Elementary School, Dimondale, Michigan. The subject population could be described as lower middle class and rural. The children were tested in a vacant classroom in their school.

B. Targets and their presentation. The visual targets were projected slides of irregular black planometric forms on a white background. The haptic targets were irregular planometric forms cut from ¼ inch (.64 cm) masonite, each mounted on a 14 inch (35.56 cm) plywood field. The forms ranged from approximately 8 inch (20.32 cm) to approximately 13 inch (33.02 cm) across their greatest extent.

As yet there is no metric for form that specifies certain dimensions along which variation would be appropriate for both touch and vision. There is some evidence from research on visual behavior (McCall & Kagan, 1967; Karmel[4]) that suggests that the amount of edge (perimeter) constituting a form is a relatively good predictor of subjects' stated preferences and looking times. Although research has not been extended to the haptic system, it seemed reasonable to vary perimeter because spatial extent as well as shape is relevant for both the visual and haptic perceptual systems.

To simplify generation of these forms, they were permitted to vary simultaneously both in perimeter and in number of angles as well. Number of angles correlates highly with perimeter but it has been found to be a slightly poorer predictor of visual behavior. While these factors need not be thus confounded, it is impossible to control for all factors. For example, number of angles could be kept constant and perimeter alone varied. However, this would necessitate vast differences in the size of the forms. Inevitably, controlling some factors leads to the confounding of others. At this point there is no end to the problem and one can only control for what past research suggests are the major factors, and leave others to vary as they may.

The forms were randomly generated and had 5, 8, 10, 14, 20 28, 36, and 48 angles in contour. (Details of the method used to generate the forms are presented in Appendix A.) There were six different forms at each level of variability, altered so as to all have the same

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[4]Personal communication, 1966.

perimeter. Perimeter varied between successive levels by a factor of 1.25[5].

The forms were presented in pairs with eight pairs in each of four blocks. Each level of variability was presented once in each block. Different counterbalanced orders of the levels of variability were designed for each block (Appendix B). The four blocks were presented in two different orders.

The first member of a form pair will be called the standard and the second the comparison. Standard and comparison forms were the same for half the pairs at each level of variability and different for the other half. These pairs within a level were distributed across blocks such that an equal number of 'same' and 'different' judgements were correct in each block with the restriction that no more than three of the same type of judgement would be correct in succession.

Standard and comparison forms were presented successively. Successive rather than simultaneous presentation was used for two reasons. First, simultaneous presentation of these forms, given their size, would have necessitated presenting them in different planes and/or in different positions relative to the children in the inter-system condition. This was thought to have certain disadvantages: In particular it would make the four conditions less nearly alike in all respects except the system to which targets were presented.

Second, this study set out to determine the role of the development of the information-organizing capacity in inter-system perception,

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[5]An exception was made for the intervals between the 8 and 10 and 10 and 14 turn forms. The interval between 8 and 14 turn forms was a factor of 1.25 with the 10-turn forms lying midway between.

and memory is an important aspect of this capacity. Successive presentation would seem to require that the child process the standard form in its entirety so as to be able to compare the second with it; a simultaneous presentation would not impose such a requirement. If children have to process all the information in the standard, it is more likely that age differences and differences within age as a function of complexity can be observed.

Standard and comparison forms were presented for as long as each child wished to explore them. The inter-target interval was 6 seconds and the inter-trial interval was approximately 8 seconds. A six second inter-target interval was used rather than a shorter time period to allow for fading of the "icon" which results when a visual target is presented and which can facilitate identification of a subsequently presented visual target (Neisser, 1966). The projection secreen was dark during the inter-trial and the inter-target intervals.

The inter-target interval was electronically controlled and the duration of presentation of standard and comparison targets was electronically timed and automatically recorded. The experimenter began a trial by advancing the carousel slide projector. The counter began cumulating elapsed time, in half seconds, simultaneously with the presentation of the target on the screen. When the experimenter terminated presentation of the standard the total elapsed time was printed out, the counter automatically reset, and the timed 6 sec. inter-target interval commenced. At the end of this interval the comparison target was automatically presented and, simultaneous with its appearance, the counter began to coumlate elapsed time during presentation of the comparison form. At a signal from the experimenter target presentation was terminated, total elapsed time was printed out, and the counter reset to zero completing the trial. Thus, the experimenter controlled the onset and offset of the standard target and the offset of the comparison target. The projector was run even during haptic exploration so that the experimenter could pace the presentation of the haptic targets. It was, of course, impossible for the children to see the target on the screen while they were exploring a target haptically.

C. Apparatus. The apparatus consisted of a 30 inch (76.2 cm) x 48 inch (121.92 cm) opaque vertical panel with a 14 inch (35.56 cm) square translucent glass screen 5 inch (12.7 cm) from the bottom of the panel and centered left to right. A carousel projector presented slides of the forms for the subjects' visual exploration from behind the panel. The panel was placed on a table in front of and 40 inches (101.6 cm) away from the subject.

The forms to be explored haptically were placed in a stand and moved to a vertical position in front of and approximately 12 inches (30.48 cm) away from the subject. Thus, both visual and haptic exploration took place with the forms in the same plane and position relative to the subject. It was impossible to present visual and haptic targets at the same distance from the subject because presenting visual forms as close to S as the tactual forms had to be placed created an 'unnatural' situation in which pilot subjects reported feeling uncomfortable.

A chin rest was attached to the edge of the table and kept the subject's head in a nearly constant position with respect to the loci of presentation of the targets. An opaque visor that could be raised

and lowered was attached to the chin rest and was used to occlude the subject's vision during haptic exploration trials.

A 1 inch (2.54 cm) diameter hole was cut in the panel 2 inches (5.08 cm) above the top edge of the projection screen. Through it a closed-circuit-television camera (CCTV) monitored the subjects' visual exploratory behavior. A second camera was placed to the side and slightly behind the subject to monitor the subjects' hand movements. A video-tape record was made of the children's exploratory behavior by means of these cameras.

D. Design and procedure. Forty-eight children at each grade level were randomly assigned to one of four treatment conditions giving each condition 12 subjects per grade level. The conditions differed with respect to the ways in which standard and comparison forms were presented for exploration. There were two intra-system conditions, one in which both forms were presented for visual exploration (V-V) and another in which they were presented for haptic exploration (T-T). In one of two inter-system conditions standards were presented for visual exploration and comparisons for haptic exploration (V-T). In the other inter-system condition the systems in which standards and comparisons were presented were reversed (T-V).

Children were brought to the experimental room one at a time and pre-tested to ensure that they understood what 'same' and 'different' meant. The pre-test consisted of 12 pairs of 2 x 2 white cards each bearing a black quadrangular form. The forms were randomly generated and equated for perimeter so as to be similar to, though smaller than, the test forms. For six pairs of the forms both members of a pair were the same, for the other six pairs, different. The pairs were presented side by side on a table in front of the child, who was then asked whether the two were the same or different. Any child making two or more errors in twelve trials was dropped from the experiment. Only one child was rejected on the basis of the pre-test.

Upon completion of the pre-test the children were told:

> I have been showing you pictures two at a time. Now I'm going to show you some more things two at a time only instead of showing you two things at the same time, I'm going to show you first one thing and then another. (Successive presentation was demonstrated with the pretest cards). And, "I'm going to show you these things over here" (a motion was made toward the apparatus.)

Children, were then seated at the table facing the apparatus and made comfortable in position at the chin rest. Those in the V-V condition were told:

> Now I'm going to show you some more funny looking pictures two at a time, first one and then another one, only you will see them through this window. O.K. Here is the first one. (A practice target was shown) Now you can look at this for as long as you want...until you think you can remember what it looks like. Then I'll show you the next one and you tell me if the next one is the same, or not the same, as this one. This is kind of a remembering game, so look at that picture until you think you can remember what it looks like. Do you think you can remember it? When you think you can remember it say 'O.K.' and I'll show you the next one.

If the child continued to look for a while longer he was asked again whether he had seen it enough and reminded to say 'O.K.' when he had. After he responded, the second (comparison) target was shown and he was asked whether it was the same as or different from the first one. He then was told that he would be shown some more pictures two at a time, and the instructions were partly repeated.

Children in the T-T condition were told:

> Now I'm going to show you some more things two at a time, only I want you to feel them rather than look at them. Do you see this funny looking thing here? (The child was shown the practice form for haptic exploration). Here, go ahead and feel it. This is going to be a feeling game and not a looking game so let me lower this visor here so you can't see this thing you're feeling. (The visor was lowered). O.K. Now here's what I want you to do. I'm going to give you things to feel two at a time, first one and then another one, and I want you to tell me if the two things are the same or different. Feel all around this first one until you have a good idea as to what it's like. As soon as you have felt it enough and you think you know what it's like, say 'O.K.' and I'll show you the next one.

The rest of the instructions were identical except for such changes as required by the change in condition.

Children in the inter-system conditions were told that they would be shown things two at a time, first something to look at (feel) and then something to feel (look at). The instructions to these subjects were essentially the same as for the intra-system conditions. Children in all conditions were not told whether or not they were correct but were told in a general way that they were performing well in the task.[6]

Children in all conditions were tested on 16 of the 32 trials without interruption. Because of the length of time taken by children in the inter-system conditions and the haptic intra-system condition (some children in the latter condition took well over 30 minutes to

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[6]Children were not told whether they were correct on each trial because: 1) it seemed desirable to avoid differential reinforcement of children, as this would be confounded with age differences in task performance, and 2) this research is concerned with the exploration strategies children use, not the strategies they can learn to use; reinforcement might shape exploratory behavior differentially as a function of age.

complete the first 16 trials) all were returned to their classroom for some period of time before completing the last 16 trials. The children were reminded of the instructions upon their return to the test room.

Most of the children remained in the classroom while another child was tested although, for some, other interruptions intervened between periods in the test room. No more than 18 hours was allowed between testing periods (as occurred when the end of the school day prevented completion of the task). Three children were eliminated from the study because they were not again present in school until more than 18 hours had elapsed. Other children eliminated from the sample were: a kindergarten girl who refused to participate beyond the pre-test, one kindergartener and one second-grader who insisted on peeking at the forms they were feeling, another second-grader who was on tranquilizer drugs, and a fifth-grader for whom two slides stuck in the projector, upsetting the inter-stimulus interval.

RESULTS

Two kinds of data were collected in the task. The first was the children's same-different judgements of the pairs of forms. The second pertained to the quality and duration of the children's exploration of the forms prior to making the same-different judgement. These data will be presented in this order followed by a discussion of the relation between the judgements and exploratory behavior.

A. Analyses of children's Same-Different judgements. Each child's same-different judgement for each pair of forms was scored 1.0 if correct and 0.0 if incorrect. Average scores for each subject and for each group of subjects ranged from approximately 0.50 (chance) to 1.0 (all judgements correct).

Two separate questions must be asked of these data: first, under what conditions did the children make more correct judgements than would be expected on the basis of chance?; second, how did the independent variables affect performance?

The effects of the independent variables were determined by a seven-factor analysis-of-variance, summarized in Table 1.

Insert Table 1 about here

The four between-subject variables were the child's Grade in school, the Condition in which the forms were presented, the Assignment of particular forms within a complexity level to an order of presentation, and the Order in which the eight levels of form complexity were presented. The three within-subject factors were level of form Complexity, type of Pair to be identified (same or different), and test Session. The level of significance used for all tests was $p < .05$.

Analysis of sub-effects (i.e., reduction of significant main effects and interactions) was carried out by Scheffe's method (1954). The level of significance used was $p < .10$. Since this test is very conservative, it has been suggested that a higher p value be used (Ferguson, 1971; Scheffe, 1959).

Finally, to check the extent of the influence of the independent variables on the children's judgements, confidence intervals were established for the proportion of correct responses expected by chance

TABLE 1

Partial Summary of Analysis of Variance of Correct Responses

Source	df	MS	F
Between			
Grade (G)	2	11.399	42.810
Condition (C)	3	14.351	53.987
G X C	6	0.648	2.434
Error	72	0.266	
Within			
Complexity (L)	7	0.930	5.330
G X L	14	0.139	0.798
Pair (P)	1	0.521	2.987
G X P	2	1.454	1.454
C X P	3	2.657	15.233
G X C X P	6	1.967	11.275
L X P	7	1.122	6.434
C X L X P	21	0.356	2.042
Sessions (S)	1	0.705	4.042
L X S	7	0.415	2.381
P X S	1	3.391	19.440
Error	2232	0.174	
Total Error	4607	951.583	

with each significant effect according to a method described by Hays (1963). These confidence intervals show the lowest value a mean can have and still be considered to be above chance, with a probability less than .05 (one-tailed) that a sample mean above that value is from a population whose mean is 0.50.

1. Effects of Grade and Condition. It was expected that children's correct responses would vary as a function of the test condition. Specifically, V-V performance was expected to be best; inter-system performance (T-V and V-T) relative to T-T performance could not be predicted. Finally, it was expected that performance in the inter-system conditions would be identical.

The results of the Condition effect ($p < .0005$) support only the first prediction: V-V children made more correct judgements than did children in any other condition ($p < .01$). There was no significant difference between V-T and T-T children but both made more correct responses than did T-V children ($p < .01$), who performed poorest of all.

The relative performance in the four conditions varied as a function of the ages of the children (Grade X Condition interaction, $p < .03$) as can be seen in Figure 1. For kingergarteners, V-V

Insert Figure 1 about here

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children did better than T-T or T-V children ($p < .05$, $p < .01$, respectively who did not differ from each other. Children in the V-T condition made more correct judgements than T-T and T-V children

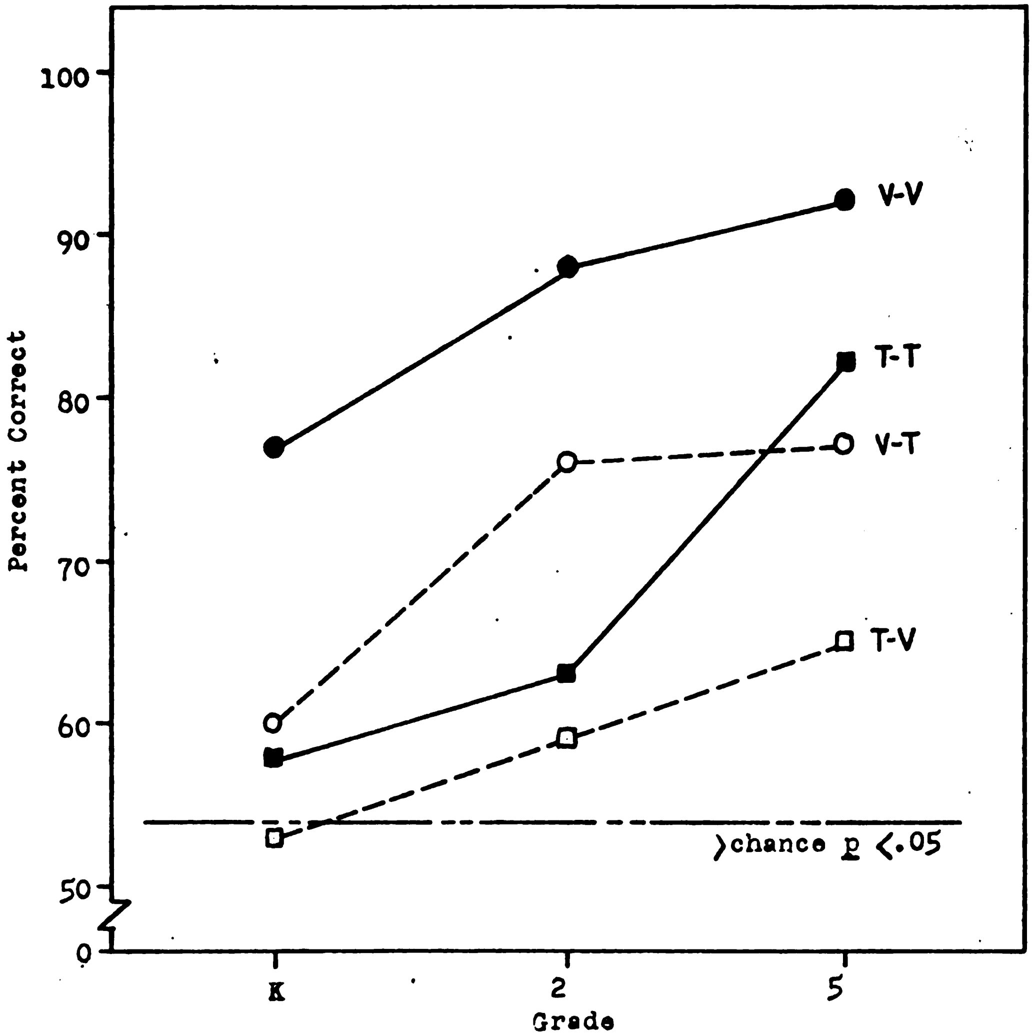

Fig. 1. Correct responses as a function of Grade and condition.

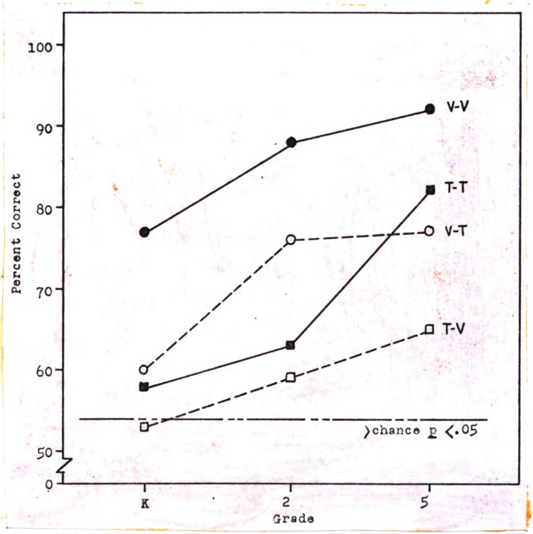

Fig. 1. Correct responses as a function of Grade and condition.

and fewer than V-V children, but these differences were not significant. Finally, except for T-V children, all kindergarteners did better than chance.

For second-graders, too, V-V children did better than T-T and T-V children ($p < .01$) who did not differ from each other. Again, the number of correct judgements by the V-T children was between that made by the T-T and T-V children in but not significantly different from either group. Second-graders in all conditions did better than chance.

Finally, for the fifth-graders, V-V children did better than T-V children ($p < .01$). The performance of children in the T-T and V-T conditions was between that of children in the other two conditions but not significantly different from either, nor did they differ significantly from each other. All fifth-graders did better than chance.[7]

To summarize these findings, V-V children did best and T-V children did poorest at all grade levels, with V-T and T-T children performing in between.

It was also expected that children's performance would improve with age; the results are consistent with this hypothesis (Grade effect, $p < .0005$). Fifth-graders made more correct judgements than second-graders ($p < .01$) who in turn made more correct judgements than kindergarteners ($p < .01$). All made more correct judgements than would be expected by chance.

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[7] In the results presented in the following pages, there were so few circumstances in which children failed to perform better than chance, it should be understood that all performance is beyond chance unless otherwise noted.

This improvement with age was not uniform, however, across the four conditions (Grade x Condition interaction). As can be seen in Figure 1, the number of correct judgements appears to increase steadily with age in all conditions although grade-level differences were significant only in the V-T and T-T conditions. In both these conditions the number of correct judgements increased significantly between kindergarten and fifth grade ($p < .01$), but most of the increase within the T-T condition occurred between second and fifth grade ($p < .075$). Additional cell comparisons show that the rate of improvement was different in the T-T and V-T conditions ($p < .01$).[8] Finally, improvement with age in the V-V and T-V conditions was not significant;[9] other differences between grade levels within these four conditions were also not significant.

Since it was expected that the levels of performance ought to be identical in the inter-system conditions (V-T and T-V) it was necessarily expected that change in performance as a function of age ought also to be identical in the two groups. Contrary to expectation, there is some suggestion that the rates are different: V-T performance improved significantly with age while T-V performance did not. On the other hand, further cell comparisons (described in footnote 8) were not significant ($p < .10$). Despite the absence of strong evidence that performance changes differently with age in the

[8] The curves were compared by doubling the value for the 2nd graders and subtracting the values for the other two age groups in each condition and testing for the significance of the difference between the resultant values for the two conditions.

[9] The magnitude of improvement in these conditions may have been diminished by floor (T-V) and ceiling (V-V) effects.

V-T and T-V conditions, any evidence that this was the case militates against the conclusion that the curves and the processes they represent are identical.

In summary, children in the V-V and T-V conditions differed from each other at all grade levels, and older children did slightly but not significantly better than younger children. Children in the V-T and T-T conditions performed at a level between that of children in the other two conditions, and children in both conditions improved significantly, though at different rates, with age.

These findings for the interaction of Grade and test Condition are most important, for they bear on certain fundamental questions to which this research was directed. These questions concern: 1) whether children included in this age range are capable of inter-system perception; 2) whether inter-system perceptual development can be distinguished from visual or haptic intra-system development; and 3) whether inter-system perception improves over the age range studied here. These questions, deriving from an associationistic theory of perception, pre-suppose the conclusion that inter-system perception is some kind of process or thing that is invoked whenever a perceptual task requires the joint functioning of two or more perceptual systems. The results suggest that this presupposition is incorrect: Differences between the V-T and T-V conditions both in the level of performance and, especially, in the developmental change found in each suggests that these tasks are not tapping some common capacity. Each of the four form-presentation conditions appears to be unique. Since the supposition on which the above questions were based is incorrect, the questions are somewhat inappropriate for these data and must be revised. It seems appropriate now to ask: 1) what are the factors that determine the relative level of performance in the four conditions and 2) what are the factors that underlie the developmental change found in the T-T and V-T conditions.

Although each of the four conditions was unique, certain features were shared with other conditions: First, in the V-V and V-T conditions, the children could only look at the standard forms, while in the T-T and T-V conditions, the standards could only be touched. Second, comparison forms could only be looked at (V-V and T-V) or touched (T-T and V-T). Third, T-V and V-T conditions required shifting between visual and haptic perceptual systems, while T-T and V-V conditions, whether or not a shift between perceptual systems was required, or some or all of these factors, could have influenced the relative levels of performance among the conditions and the developmental change found in them.

2. Effects of mode of presentation of standard forms. Since vision seems to be much more efficient than touch for the perception of form, it is reasonable that children who looked at the standards should have obtained more or better information and consequently made more correct judgements than children who only touched them. The effects of the method of presentation of the standard can be assessed by comparing the scores of children in the V-V and V-T conditions with the combined scores of children in the T-V and T-T conditions.

When the standard forms were presented visually, performance was better than when they were presented haptically ($p < .01$). This was true at all grade levels, though significant only for the second-graders ($p < .05$). Differences between groups within the visual

(V-V and V-T) and haptic (T-T and T-V) standard-presentation conditions were not significant at any grade level. Therefore it seems that the superior performance of children in the visual relative to the haptic standard-presentation conditions is a joint effect of the combined treatment conditions rather than the result of any one.

Although performance was better with visual than with haptic presentation of the standards, performance seems to have improved with age only in the haptic conditions. In the haptic conditions, the number of correct judgements increased between kindergarten and fifth-grade ($\underline{p} < .075$). Both the T-T and T-V groups appear to contribute about equally to this change. In the visual conditions, improvement with age was small and not significant.

3. Effects of mode of presentation of comparison forms. Was the method of presenting the comparison forms related to incidence of correct judgements? To answer this question the number of correct judgements for groups V-V and T-V were combined and compared with the combined performance of groups V-T and T-T.[11] Differences between visual and haptic presentation of comparisons proved to be non-significant for the grade levels combined as well as for any individual grade level.

Improvement with age was significant among children in the haptic conditions, between kindergarten and fifth grade ($\underline{p} < .05$); improvement in the visual conditions was smaller and not significant. While it

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[11] Although children in the V-V condition differ from children in the T-V condition at each grade level the rate of development across grade in the two conditions is almost exactly the same so there is some basis for combining these data.

seems correct to conclude that groups T-T and V-T are both contributing to the improvement in the haptic comparison-presentation it is clear that improvement is not identical in the two groups: improvement occurs at different times in the two conditions and a comparison of the curves (described in footnote 8) shows them to be significantly different ($p < .01$).

4. Results pertaining to inter-system and intra-system presentation of standard and comparison forms. A third possible basis for distinguishing among the four experimental conditions is that conditions T-T and V-V require intra-system perception of standard and comparison forms while conditions T-V and V-T require inter-system perception. Performance in the intra-system tasks should be better than in the inter-system tasks because not all features of form that can be seen can be felt and vice-versa. Correct judgements can be made only when a feature distinguishing a standard form can be identified on a comparison form. Children using both vision and touch should make more errors than children using vision or touch alone because they occasionally should detect a distinctive feature of a standard with one perceptual system that they cannot detect with another. Younger children especially should make more inter-system than intra-system errors.

The results generally bore out these predictions. Children in the intra-system conditions made significantly more correct judgements than did children in the inter-system conditions ($p < .01$), although this difference was significant only for all ages combined. There was also improvement with age among children in the intra-system conditions between kindergarten and fifth grade ($p < .05$) although this is probably due primarily to improvement in the T-T condition: Differences between the T-T and V-V conditions were significant at kindergarten and second grade though not at fifth grade; there was significant improvement in performance with age in the T-T but not in the V-V condition; comparing the curves (footnote 8) shows them to be different ($p < .05$). There was no improvement with age in the combined scores of children in the inter-system conditions.

In summary, these analyses show that the relative level of performance in the four conditions is determined by 1) the perceptual system to which the standards were presented and 2) whether or not the standards and comparisons were presented to the same perceptual system. These analyses also show that haptic perception, especially of the standards, and less clearly, of the comparisons, underlies improvement with age in these conditions. Inconsistencies in age change in the conditions involving touch, however, show that it is likely to be the way haptic perception was used in each task and not haptic perception in general that is important for the developmental change observed.

5. Effects of form Complexity. It was expected that highly complex forms would be correctly identified less often than forms of low complexity because highly complex forms, being comprised of more features, would make a greater demand on memory. This expectation was borne out. As can be seen in Figure 2, the number of correct judgements

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Insert Figure 2 about here

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generally decreased across the eight levels as form complexity increased

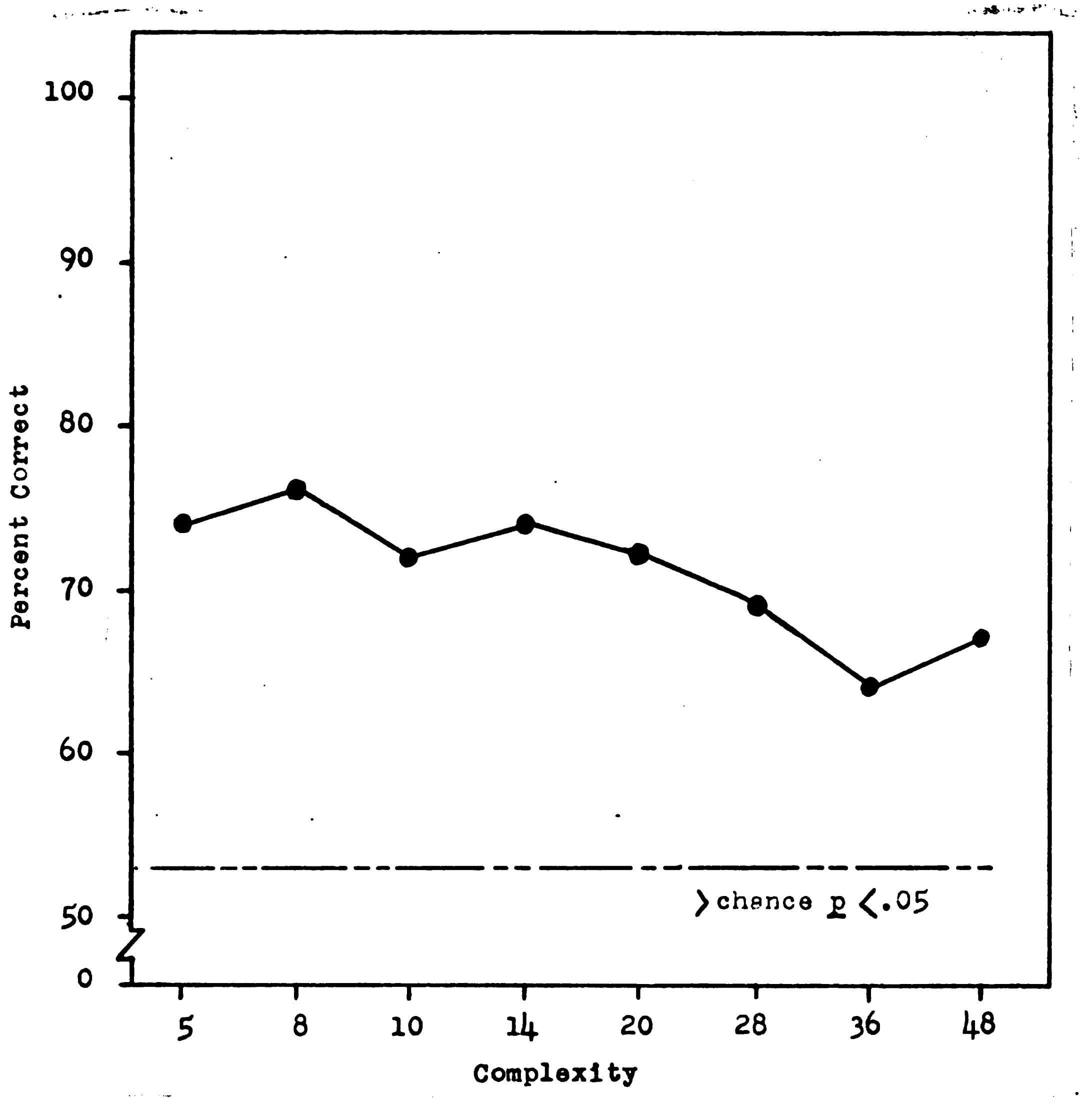

Fig. 2. Correct responses as a function of form Complexity.

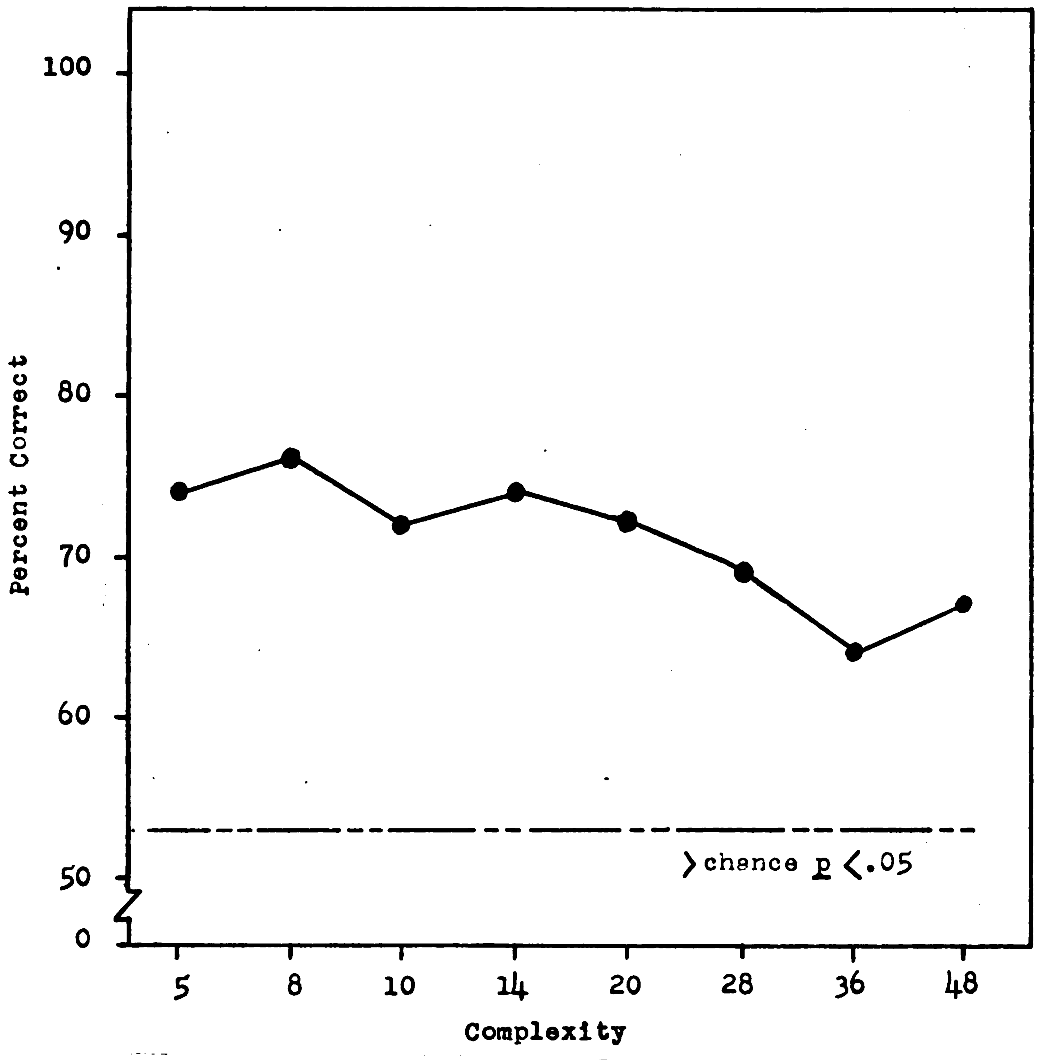

Fig. 2. Correct responses as a function of form Complexity.

(p < .0005). Most of the complexity effect can be attributed to differences between the 5-, 8-, and 14-sided vs. the 36- and 48-sided forms (p < .01-.10).

It also was expected that young children would have more difficulty with more complex forms than would older children. The non-significant Grade x Complexity interaction (p < .10) indicates that this prediction was not borne out.

Finally, it was expected that correct judgements would increase with practice, especially for the high complexity forms. That is essentially what happened. Children made somewhat fewer errors in Session II than in Session I (Session effect, p < .04), and across sessions the number of correct identifications of the most complex forms increased relatively more than correct identifications of less complex forms as can be seen in Figure 3 (Session x Complexity effect

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Insert Figure 3 about here

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p < .02). However, differences between sessions at each complexity level and within sessions between complexity levels were small and not significant.

6. Effects of type of form pair. Past research suggests that whether the forms to be compared are the same or different is an important determinant of success. A sufficient condition for judging forms "different" is finding any difference between them, while a necessary condition for judging forms the same is finding them identical in all respects. Therefore, same pairs would require much more careful and lengthy exploration than different pairs. The difference between same

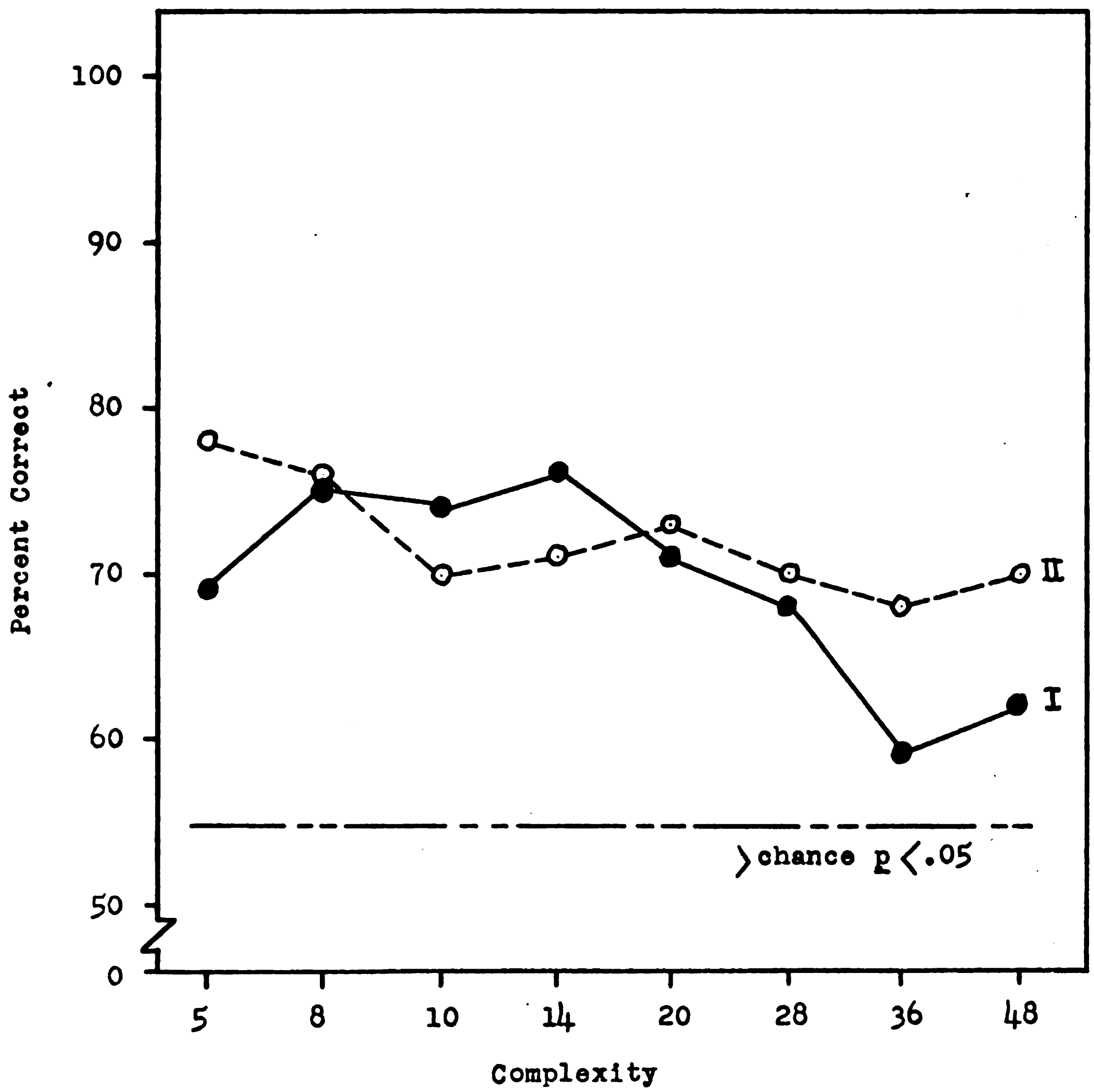

Fig. 3. Correct responses as a function of Session and Complexity.

and different pairs in required exploration would be much greater for high than for low complexity forms. Therefore, same pairs, especially the highly complex ones, should be more difficult to identify than different pairs. Highly complex same pairs should also be more difficult to identify for younger than older children since the need for lengthy exploration and the information processing associated with it should be greatest for those forms and more difficult for younger than for older children to accomplish.

The results are in some way <u>in</u>consistent with these hypotheses. In general, same pairs were more often correctly identified than different pairs, although this difference was in fact very small (.72 <u>vs</u> .70, $p < .08$). The difference between same and different pairs was not related to complexity level in any simple or consistent way as can be seen in the <u>Complexity</u> X <u>Pair</u> interaction ($p < .0005$) shown in Figure 4.

Insert Figure 4 about here

Other findings were as expected. Identification of different pairs was unrelated to complexity while same pairs were somewhat easier to identify when they were less complex: the difference between 8- and 48-sided same pairs was significant ($p < .10$).

The hypothesized relation between type of pair and the age of the children also received some support as can be seen in the <u>Grade</u> X <u>Pair</u> interaction ($p < .0005$) presented in Figure 5. Although differences between same and different pairs were not significant at any

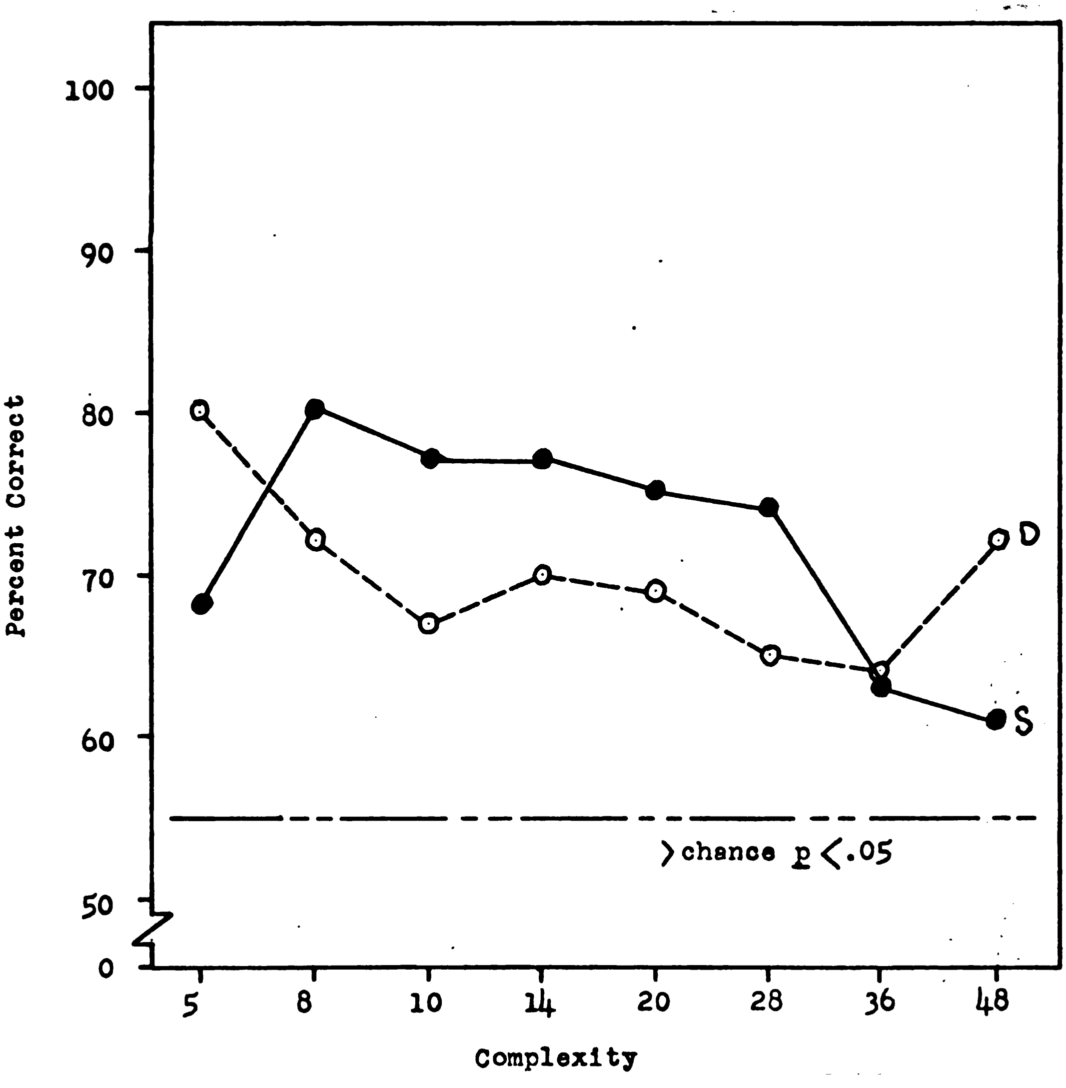

Fig. 4. Correct responses as a function of Complexity and type of form Pair.

Insert Figure 5 about here

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any grade level the rate of improvement in performance with age was greater for same than for different pairs. In general, performance across age on same pairs started lower and ended higher than performance on different pairs; the difference between kindergarteners and fifth-graders was significantly larger for same than for different pairs ($p < .05$). For same pairs, kindergarteners, second-graders, and fifth-graders all differed from each other ($p < .10$-$.01$), while for different pairs, kindergarteners differed from fifth-graders ($p < .05$).

Consistent with the effects of age, practice led to improved performance for same but not for different pairs (Pair X Session interaction, $p < .0005$) as can be seen in Figure 6. Across sessions,

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Insert Figure 6 about here

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performance on same pairs improved ($p < .01$) while performance on different pairs did not change. In session I same and different pairs were identified about equally well while in session II same pairs were identified correctly more often than were different pairs ($p < .05$).

Performance on same and different pairs also varied with the treatment condition (Pair X Condition interaction, $p < .0005$), shown in Figure 7. Except in condition V-T, same pairs were easier to judge

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Insert Figure 7 about here

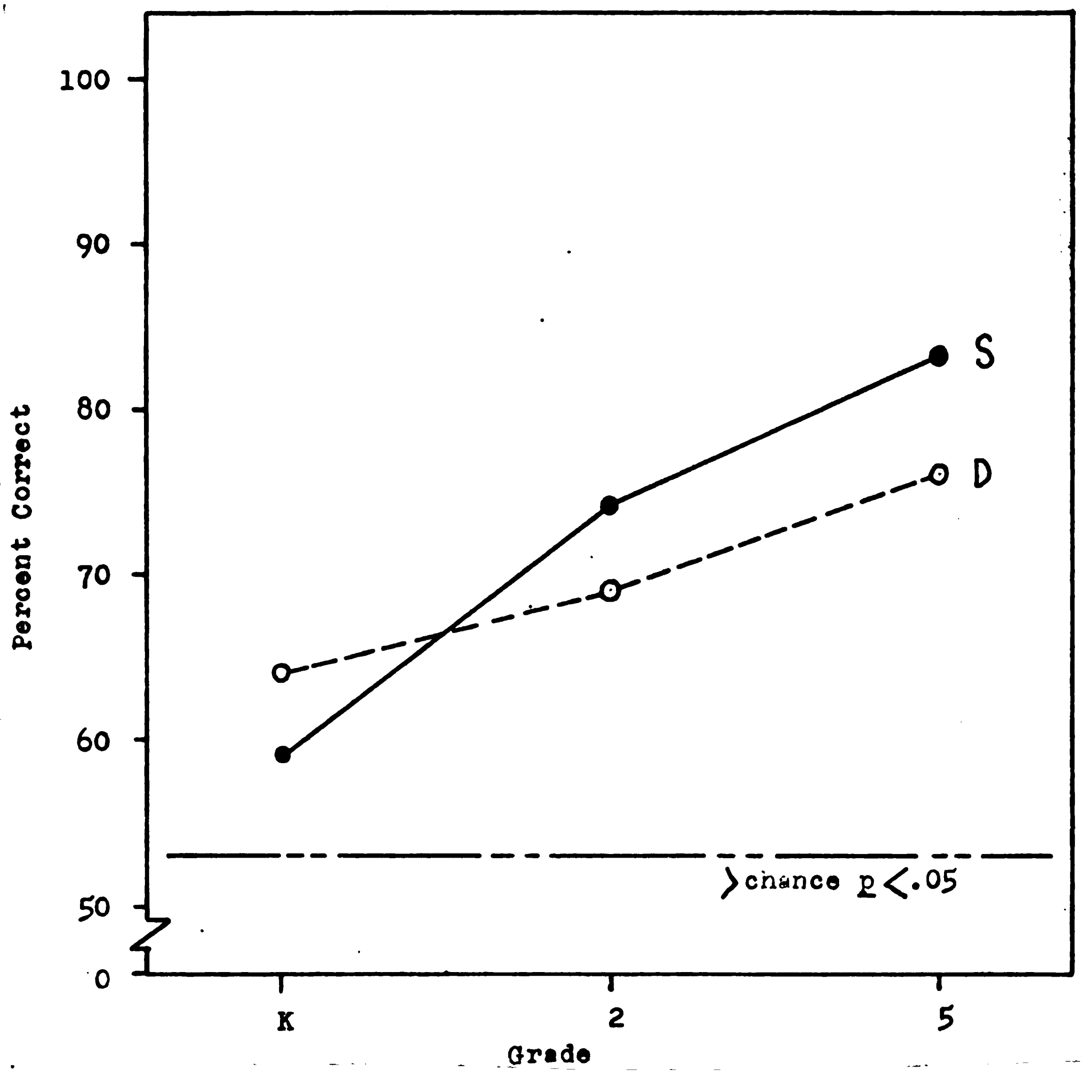

Fig. 5. Correct responses as a function of Grade and type of Pair.

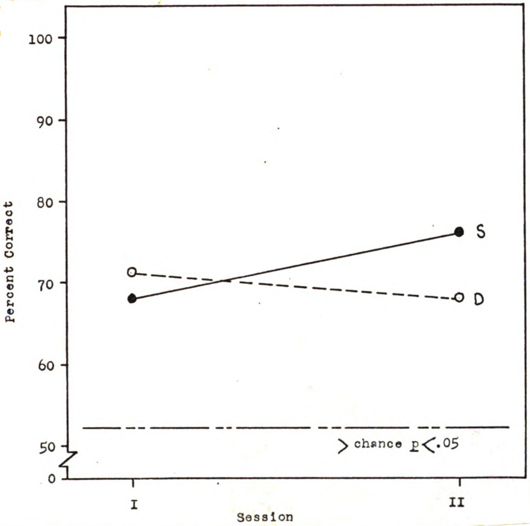

Fig. 6. Correct responses as a function of type of Pair and test Session.

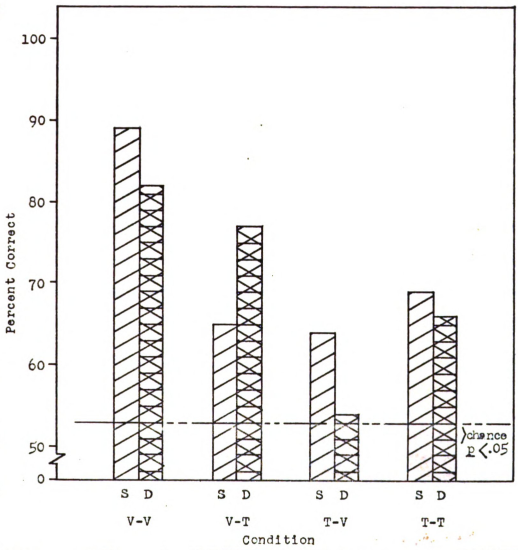

Fig. 7. Correct responses as a function of type of Pair and Condition.

than different pairs. The only significant pair differences were in the V-T and T-V conditions, however. Same pairs were judged correctly about as often under both conditions, but different pairs were judged correctly, relative to same pairs, more often in the V-T condition ($\underline{p} < .05$) and less often in the T-V condition ($\underline{p} < .075$).

Children in Group V-V made more correct judgements of same pairs than V-T, T-V and T-T children ($\underline{p} < .01$), who did not differ from each other. Children in Groups V-V and V-T made more correct judgements of different pairs thatn Group T-T children ($\underline{p} < .05$-.10), who in turn made more correct judgements than Group T-V children ($\underline{p} < .05$). No explanation for these differences can be offered.

Pair and Condition also interacted with Complexity ($\underline{p} < .004$) but scrutiny of differences between cell means in this interaction sheds no light on the role of complexity in the pattern of results described above. Differences between types of pairs were not significant at any complexity level in any of the conditions, and differences between complexity levels were not significant for either same or different pairs in any of the conditions.

Performance improved with age in the T-T and V-T conditions and the significance of the interaction of Grade and Condition with type of Pair ($\underline{p} < .0005$) suggests that improvement in those conditions might have reflected improvement with one type of form pair. Only the improvement in the T-T condition was clearly related to the type of pair: identification of same pairs improved between kindergarten and fifth-grade ($\underline{p} < .05$). In the other conditions (V-T and also V-V and T-V) the improvement in identification of same pairs with age was small and not significant. In no condition did the identification of different pairs change with age. Other differences, as between pairs in any age in any condition, were not significant.

B. Analyses of children's exploratory behavior. Exploratory behavior was recorded to permit analysis of the relation between exploration and correct identification of form pairs. Two kinds of data were collected. The first consisted of how long the children either looked at or felt the forms; the second consisted of characterizations of specific aspects of their actual hand movements.

1. Analysis of duration of visual and haptic exploration and the relation between duration and the number of correct judgements. Durations of exploration were recorded for all children in all conditions on all trials, so it was possible to analyze the variation in these scores by means of the same model analysis-of-variance used in the analysis of the number of correct judgements. Two seven-factor analyses of variance were performed, one for standard and one for comparison exploration. For analyses of sub-effects, Scheffe's method again was used. The results of these analyses are summarized in tables 2 and 3.

Insert Tables 2 and 3 about here

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2. Relation between duration of exploration of standards and correct judgements. The accuracy with which the children identified form pairs ought to be related to the adequacy of their exploratory behavior such that the same variables ought to be associated with both correct responses and exploration time. A first step toward showing

TABLE 2

Partial Summary of Analysis of Variance of Exploration-time for Standard Forms

Source	df	MS	F	p
Between				
Grade (G)	2	15941.420	5.172	.008
Condition (C)	3	99555.994	32.302	.0005
G X C	6	4581.799	1.487	.10
Error	72	3081.986		
Within				
Complexity (L)	7	8190.649	139.740	.0005
G X L	14	493.111	8.413	.0005
C X L	21	1204.619	20.552	.0005
G X C X L	42	105.163	1.794	.001
Pair (P)	1	50.278	0.858	.10
L X P	7	598.962	10.219	.0005
C X L X P	21	144.906	2.472	.0005
Sessions (S)	1	19952.766	340.413	.0005
L X S	7	409.086	6.979	.0005
L X P X S	7	938.493	16.012	.0005
Error	2232	58.613		
Total Error	4607	1137295.268		

TABLE 3

Partial Summary of Analysis of Variance of Exploration-time for Comparison Forms

Source	*df*	*MS*	*F*	*p*
Between				
Grade (G)	2	3368.767	2.644	.078
Condition (C)	3	64449.884	50.600	.0005
G X C	6	2477.357	1.945	.085
Error	72	1219.433		
Within				
Complexity (L)	7	3025.508	66.306	.0005
G X L	14	95.827	2.100	.010
C X L	21	736.352	16.138	.0005
G X C X L	42	68.284	1.496	.021
Pair (P)	1	217.303	4.762	.028
L X P	7	163.023	3.357	.001
G X C X P	6	34.850	0.764	1.0
Sessions (S)	1	3939.506	86.337	.0005
C X S	3	616.317	13.507	.0005
L X S	7	45.213	0.991	.10
G X C X S	6	112.230	2.460	.023
L X P X S	7	108.273	2.373	.020
Error	2232	45.630		
Total	4607	629238.904		

a link between exploration and correct responses consists of looking for concommitant variation between them.

a. Effects of Grade and Condition. A glance at the exploration time scores for standard forms reveals wide variation in exploratory behavior. Analysis of variance indicated many significant effects and interactions and, of these, the effects of Grade ($p < .0008$), Condition ($p < .0005$), and their interaction are of primary interest. The length of exploration time increased from kindergarten to second grade to fifth grade, with only the kindergarteners and fifth graders different from one another (Grade effect, $p < .01$).

At this point, the results suggest some relation between exploration time and response accuracy, since fifth-graders also made more correct identifications than kindergarteners, but the particularities of this relation will be explored later.

As would be expected, the main contribution to the Condition effect was the difference between the two means of exploring the standards: children who looked at the standards (V-V and V-T conditions) looked at them for a significantly shorter time ($p < .01$) than did children who felt the standards (T-V and T-T conditions).

The children were told how the forms would be presented, and every pair of forms, including a practice pair, was presented in the same way. Therefore it is reasonable to ask whether the children varied their exploration times for standard forms depending on whether they would subsequently explore the comparisons with the same or with a different perceptual system.

Children who looked at the standards tended to look longer when they would subsequently feel than when they would subsequently look at the comparisons (mean looking times: 5.93 seconds for V-V subjects, 10.38 for V-T subjects). Children who felt the standards, however, showed an even greater difference in their standard-exploration times depending on whether they subsequently looked at or felt the comparisons: standards were explored longer in the T-V than in the T-T condition (means: 26.62 and 19.74, respectively, $p < .05$).

The V-T condition was more difficult than the V-V condition, and the T-V condition was more difficult than the T-T condition, as shown by the number of correct judgements made by children in those conditions. Therefore, it appears that children adjusted their exploratory behavior according to the difficulty of the task. Although older children might be expected to be more sensitive to and make more of an adjustment to a difficult task than younger children, such was not the case: older and younger children's exploration times were not different in any of the conditions (Grade X Condition interaction, $p < .10$).

b. Effects of form Complexity. It was expected that children's exploration times would increase directly as form complexity increased and that older children would be more influenced by form complexity than younger children. These expectations were supported by the results. The significant Complexity effect ($p < .0005$), presented in Figure 8, shows that more complex forms were explored longer than less

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Insert Figure 8 about here

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complex forms; the differences between successive complexity levels were approximately equal. In other words, the constant rate of

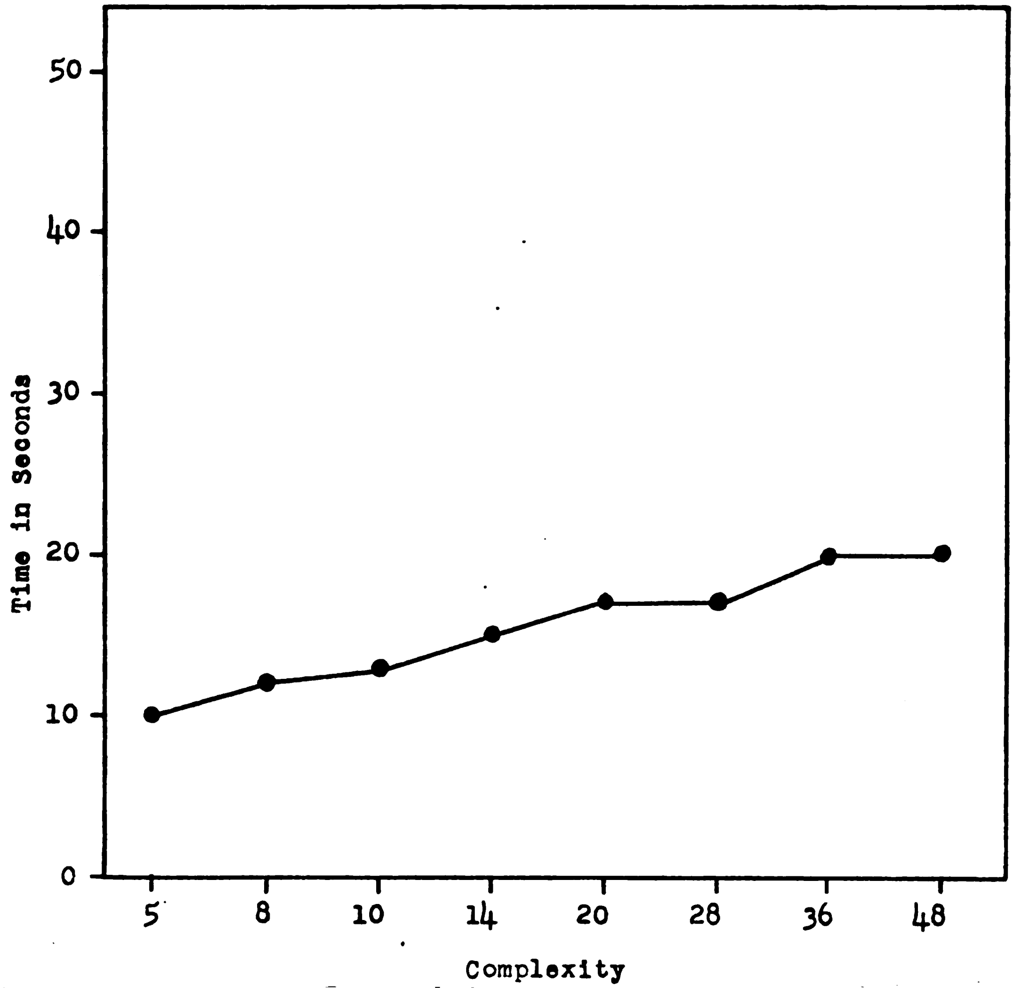

Fig. 8. Standard exploration time as a function of form Complexity.

increase in perimeter of the forms across complexity levels was related to a constant rate of increase in children's standard-exploration time. This effect depended also on the age of the child (Complexity X Grade interaction, $p < .0005$) as can be seen in Figure 9. In

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Insert Figure 9 about here

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general, there were no differences between grade levels in exploration time for forms of low complexity but, for the more complex forms, the older children increased their exploration time relatively more than did the younger children.

Specifically, children at all grade levels explored 5-, 8-, and 10-sided forms about equally. When given 36- and 48-sided forms, however, fifth-graders increased their exploration times significantly more than did kindergarteners ($p < .01$). Second-graders showed an intermediate rate of increase. Fifth-graders explored 20-, 28-, 36-, and 48-sided forms longer than kindergarteners ($p < .05$-$.01$) while second-graders' exploration times were in between. Finally, kindergarteners explored the two most complex forms more than the two least complex forms ($p < .05$).

These findings evidence no simple relation between exploration time and correct responses. Fifth-graders increased their exploration time more for high complexity forms than did the kindergarteners. If it can be assumed that the fifth-graders took just as much time to explore as they needed, one would expect that younger children took considerably less time than they really needed especially to explore the high complexity forms. Consequently, they would have made more errors

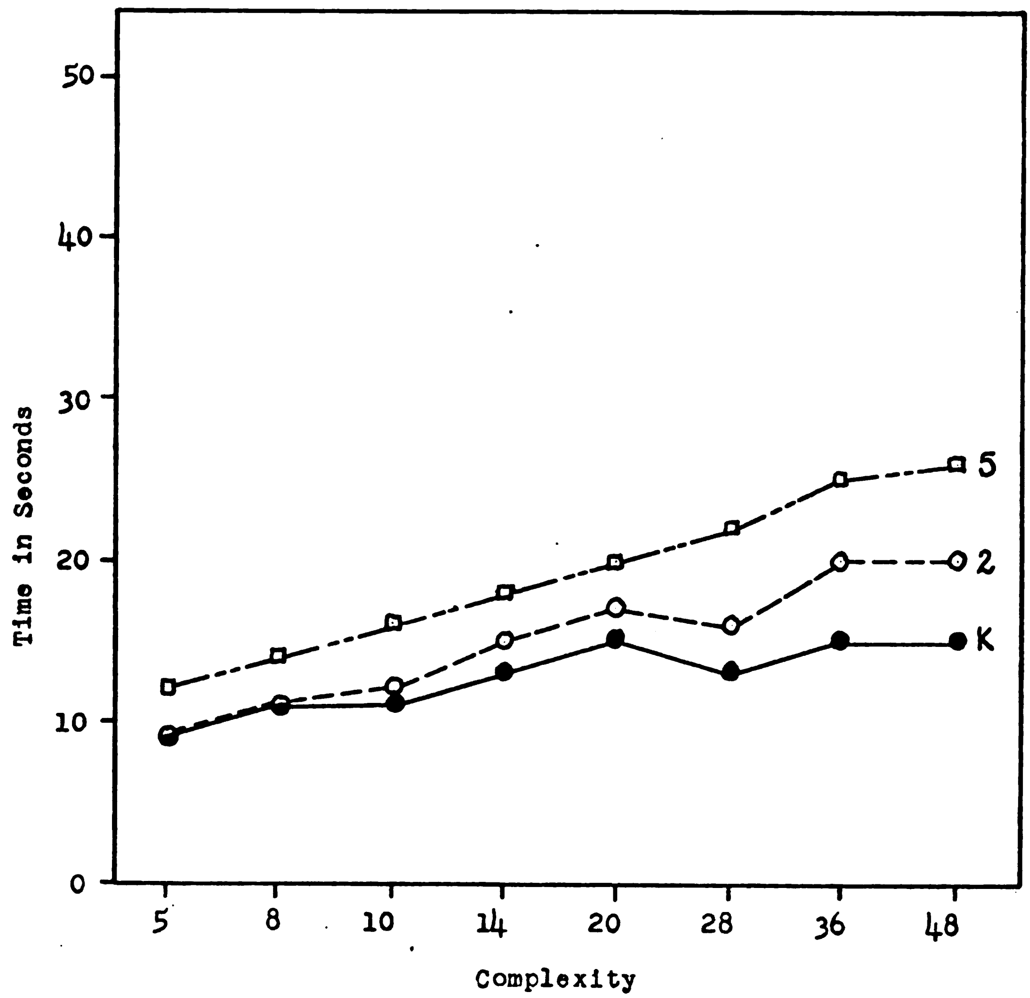

Fig. 9. Standard exploration as a function of form Complexity and Grade.

with those forms relative to the older children. Contrary to this prediction, there was no joint effect of age of the children and form complexity on correct responses.

The effects of form complexity also depended on how the forms were presented (Complexity X Condition interaction, $p < .005$) as shown in Figure 10. Children in conditions T-V and T-T explored the more

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Insert Figure 10 about here

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complex standards longer than the less complex ones, but children in the V-V and V-T conditions did not. Specifically, children in the visual conditions looked at the standard forms for a shorter time than children in the haptic conditions felt them, and this difference held at all levels of form complexity ($p < .01$). Also, the difference between visual and haptic exploration increased with increasing complexity; the difference between the visual and haptic conditions was significantly greater for the average of the four high complexity levels than the average of the four low complexity levels ($p < .01$).

This difference between the visual and haptic standard-exploration times, especially for the more complex forms, was greater for older than for younger children (Complexity X Condition X Grade interaction, $p < .001$). This interaction is presented in Figure 11. The extent

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Insert Figure 11 about here

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to which children's feeling times exceeded their looking-times was about the same at all grade levels for the low complexity forms. For

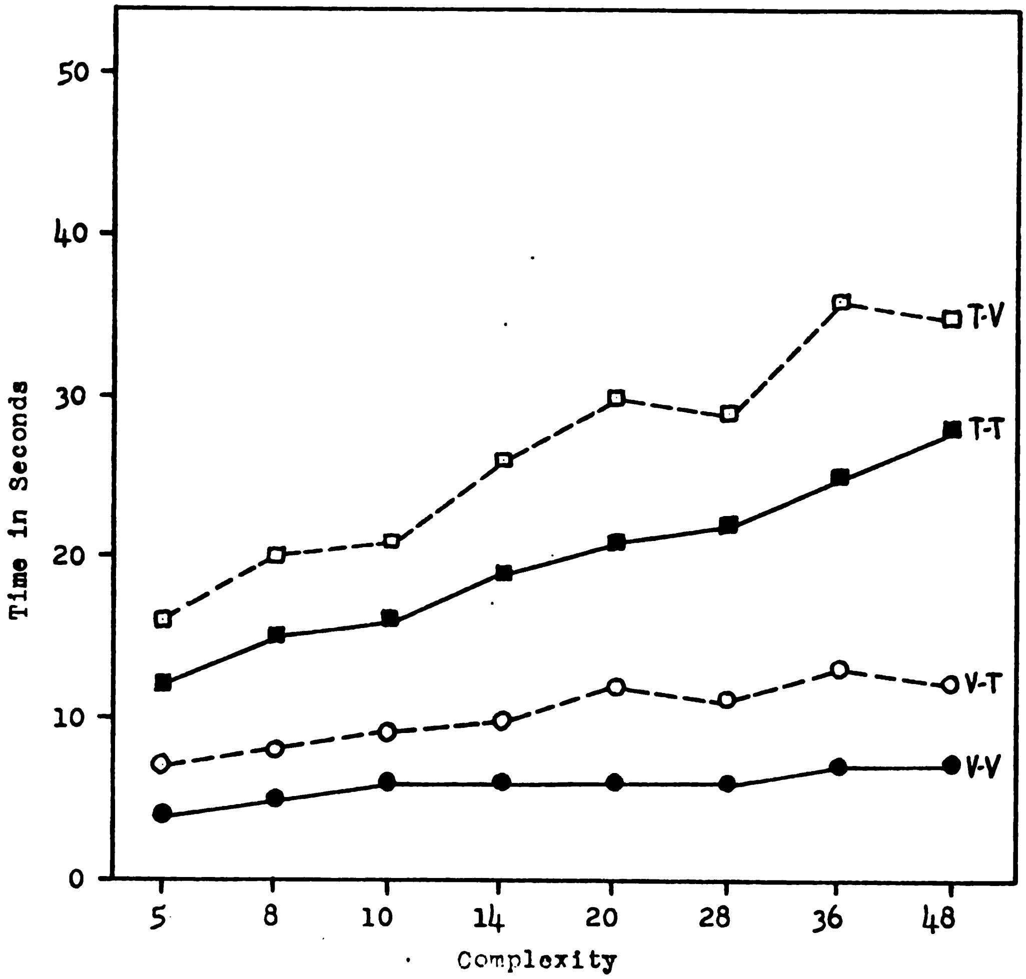
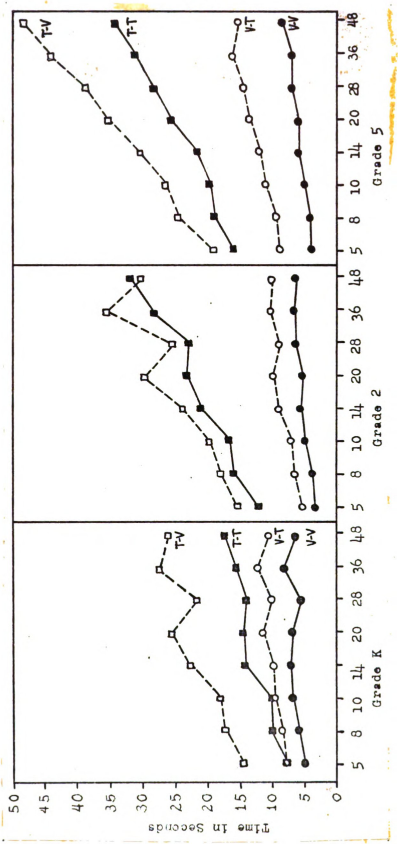


Fig. 10. Standard exploration time as a function of form Complexity and Condition.

Fig. 11. Standard exploration time as a function of form Complexity, Condition, and Grade


Time in Seconds
Grade K
Grade 2
Grade 5
T-V
T-T
V-T
V-V
0
5
10
15
20
25
30
35
40
45
50
5
8
10
14
20
28
36
48

high complexity forms, the extent to which feeling-times exceeded looking-times increased with the children's grade level although not significantly. However, this differential rate of increase as a function of age is reflected in the greater number of significant differences between looking- and feeling-times for more complex forms among older relative to younger children. For fifth-graders, the differences between the looking and feeling conditions were significant for each of the four most complex forms ($p < .01$); for second-graders, the differences were significant for three of the four most complex forms ($p < .05$-$.01$); for kindergarteners, none of these contrasts was significant. Visual and haptic exploration times for the three least complex forms were not significantly different at any grade level.

c. Differences between visual and haptic exploration. The differences between visual and haptic exploration as a function of form complexity and grade level (Figure 11) may have resulted from changes in visual or haptic exploration, or both. Consequently, changes with age and complexity in visual and haptic exploration times must be looked at separately. In the visual standard-exploration conditions (V-V and V-T), complex forms were looked at only slightly longer than simple (low complexity) forms, and the differences were not significant across age or at any age alone. In addition, children at all ages looked at the forms at each complexity level for approximately the same length of time. Finally, there were no significant differences within or between the V-V and V-T conditions associated with form complexity or subjects' grade level. In other words, the children, young and old alike, who looked at the standard forms looked at them for approximately an equivalent length of time whether the forms were simple or complex.

This finding is particularly interesting because past research with similar forms suggests that visual exploratory behavior varies as a function of the complexity (perimeter) of the forms. But in that research children either were asked to verbally express their preferences for forms or were allowed to look at forms for as long as they liked in free-looking tasks. The present results show very clearly that the complexity (perimeter) of random shapes is not a factor in visual exploration time when the subject's task is to identify the form.

On the basis of these data for the visual standard-exploration conditions, it appears that the age and complexity differences between visual and haptic exploration are due to variation among subjects in the haptic conditions (T-T and T-V) alone. Comparisons of means within the haptic conditions support this conclusion. Children for whom the standards were presented haptically felt the four most complex forms significantly longer than they felt the four least complex forms ($p < .01$). Furthermore, group T-V children showed a greater increase in exploration time as complexity increased than did T-T children. Differences between the two conditions were significant for the five highest but not the three lowest complexity levels ($p < .050$-$.01$).

Group T-V children felt the four most complex forms longer than the four least complex forms ($p < .01$, Condition X Complexity interaction), especially the fifth-graders (Condition X Complexity X Grade interaction). For kindergarteners, there were no differences in feeling time across complexity levels, while for second- and fifth-graders at least one high complexity form was explored longer than a low complexity form ($p < .01$). The difference in feeling time between a low (5-sided) and a high complexity (48-sided) form was significantly greater for fifth-graders than for kindergarteners ($p < .075$). The second-graders were in between and not significantly different from either age group.

For the Group T-T children the four most complex forms were felt longer than the four least complex forms ($p < .01$, Condition X Complexity interaction) but there was only a suggestion of age differences in this effect (Condition X Complexity X Grade interaction). Fifth- and second-graders did feel one of the high complexity forms longer than one of the low complexity forms ($p < .05$-$.01$), while kindergarteners did not.

To summarize, the time children looked at the standards was not related to their age (grade), test condition, form complexity, or whether the comparison forms subsequently presented were looked at or felt. By contrast, children who felt the standards felt high complexity forms longer than low complexity forms, more so in the T-V than in the T-T condition. Further, this difference was more marked among older than among younger children. Put another way, older children varied their haptic exploration of the standard forms more than younger children, and this variation depended upon the complexity of the forms and the perceptual system in which comparison forms were subsequently presented.

Finally, none of these age differences in exploration-time seem to be related to age differences in correct judgements. Although grade differences in exploration-time interacted with form complexity and condition together, grade did not interact with condition alone. Variation in correct judgements was related to grade and condition alone but not in conjunction with form complexity. In view of these inconsistencies between judgement and exploration-times, it seems unlikely that exploration-time differences could have produced the variation in the number of correct responses.

d. Effects of test session. It might be expected that children's exploration would decrease with practice as they become more efficient in the task. The results are consistent with this hypothesis: children's exploration time was less in Session II than in Session I (Session effect, $p < .0005$). The decrease was greater for high than for low complexity forms (Session X Complexity interaction $p < .0005$, shown in figure 12). Forms at all complexity levels tended to be

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Insert Figure 12 about here

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explored less in Session II than in Session I although differences between sessions were significant only for the five highest complexity levels ($p < .01$).

The results for correct responses show that children made more correct identifications in Session II than in Session I, mainly it seems, because their ability to identify more complex forms had improved. Therefore, improved performance is associated with a decrease in exploration time.

e. Effects of type of form Pair. A child would not have been able to predict what type of comparison form would follow the standard that he was exploring. It was therefore reasonable that a comparison form, whether the same as or different from the standard it followed, did not affect the length of exploration of the standard (Pair effect,

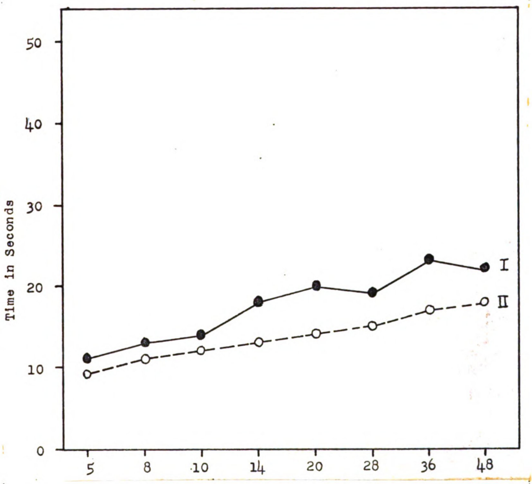

Fig. 12. Standard exploration time as a function of test Session and form Complexity.

p < .36). It was surprising, however, that type of Pair interacted with Complexity (*p* < .0005), Complexity and Session (*p* < .0005) and Complexity and Condition (*p* < .0005). Examination of cell means in these interactions revealed no consistent effect of type of Pair. It is possible that standard exploration time might have been influenced by the type of pair presented on the preceding trial, but the data have not been examined to test this hypothesis.

3. Relation between duration of exploration of comparisons and correct judgements. Many factors might determine children's exploration time for comparison forms but the most important is likely to be whether or not the comparison is the same at the standard. When forms are different, detecting any difference at all between them is sufficient for a judgement to be made; but when they are the same, the subject must be certain that they are the same in every respect. Therefore, when comparison forms are the same as the standards, exploration should be of longer duration than when they are not. Comparison exploration ought also to vary as a function of whether the same perceptual system was used to explore the standard: Comparisons should be explored longer when children must use a different system than when they use the same system as they used to explore the standards.

a. Effects of Grade and Conditon. Since comparison exploration should be more thorough for same than for different pairs, exploration of same comparisons ought to be more nearly like standard exploration than different comparisons. Therefore, comparison exploration times ought to have varied like the standards, as a function of Grade and Condition for same pairs but not necessarily for different pairs. Type of Pair did not interact with Grade and Condition however; variation in exploration as a function of Grade and Condition apparently was the same for both types of form pairs. There were essentially no age differences in comparison exploration times: The effect of Grade was only marginally significant ($p < .078$), and differences between grade levels were not significant. Cell analyses within the significant Condition effect ($p < .0005$) showed that the comparison forms were felt longer than they were looked at (T-T and V-T times exceeded V-V and T-V times, $p < .01$). Other differences between conditions were small and not significant.

The differences between looking and feeling times for the comparisons were only marginally related to the ages of the children (Condition X Grade interaction, $p < .085$). The only significant differences were between visual and haptic exploration of the forms: haptic exceeded visual exploration times among fifth- and second-graders ($p < .05$) but not among kindergarteners. Finally, comparisons were explored only slightly longer in the inter-system than in the intra-system conditions and these differences were not significant.

In view of the marginal significance of these findings and the fact that the pattern of results does not correspond to the pattern of results for correct responses, there seems to be but weak evidence to suggest that variation in exploration time of comparison forms as a function of grade and condition produced the observed variation in correct judgements.

b. Effects of form Complexity. Comparison exploration should have been influenced by form complexity in much the same way as was standard exploration: Older children ought to have exceeded younger

children in their exploration of high complexity forms. Also variation in form complexity ought to have had greater effects on haptic than on visual exploration. The results showed that exploration time increased as complexity increased (Complexity effect, $p < .0005$) and, although differences between successive complexity levels were not significant, the four most complex forms were explored longer than the four least complex forms ($p < .01$).

Generally, children of all grade levels explored the more complex comparisons longer than the less complex ones; older children, second- and fifth-graders, explored comparisons longer than kindergarteners, and did so more as complexity increased (Grade X Complexity interaction, $p < .01$), shown in Figure 13). Exploration times for

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Insert Figure 13 about here

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second- and fifth-graders were slightly but not significantly higher than kindergarteners for the least complex forms and, as complexity increased exploration times increased, more markedly for the older children than for the younger ones. Fifth- and second-graders both explored 48-sided forms longer than kindergarteners ($p < .05$-$.01$).

As expected, the effects of form complexity on exploration were produced when comparisons were explored haptically but not when they were explored visually (Complexity X Condition interaction, $p < .005$) as shown in Figure 14. There were no differences within either visual

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Insert Figure 14 about here

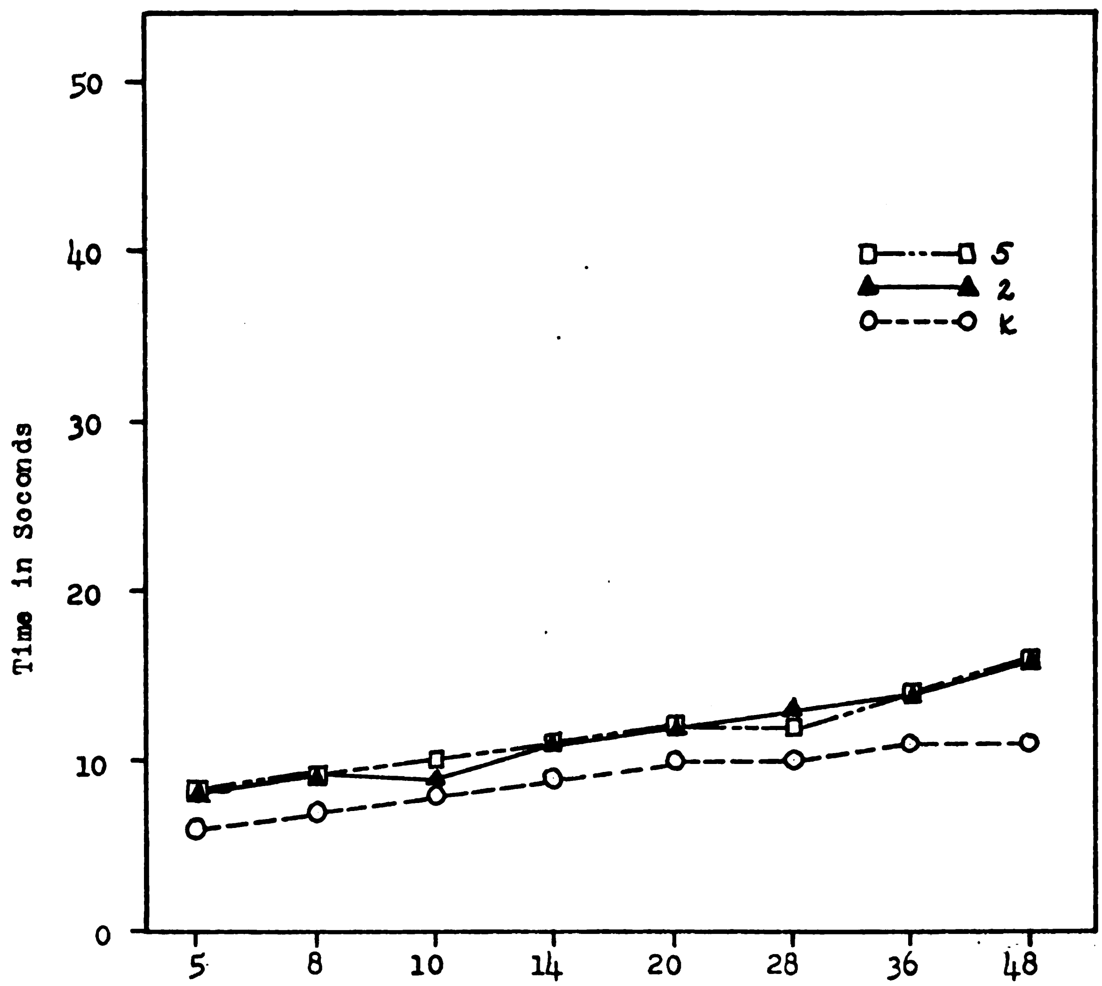


Fig. 13. Comparison form exploration time as a function of Grade and Complexity.

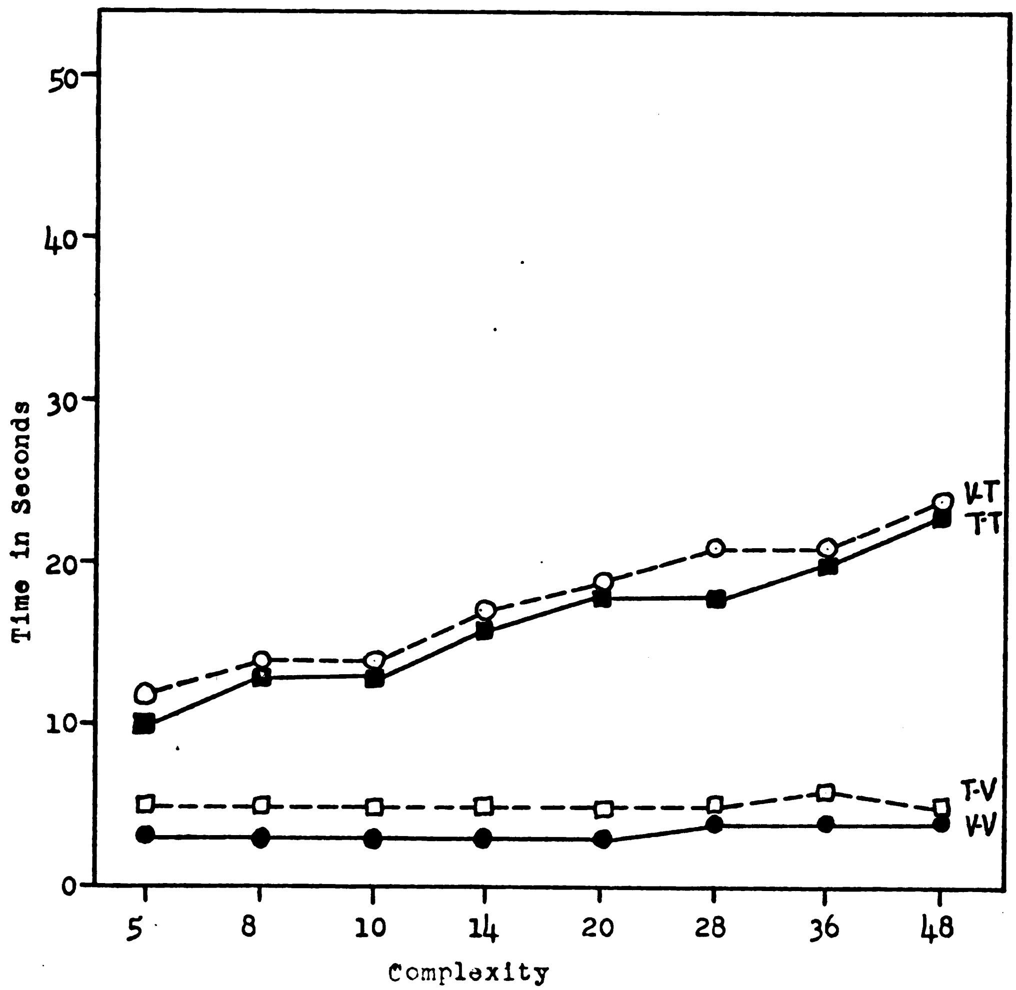


Fig. 14. Comparison form exploration time as a function of Complexity and Condition.

comparison-exploration conditions (V-V and T-V) across complexity levels nor were there differences between these condition at any complexity level. This was true regardless of age (Complexity X Condition X Grade interaction, $p < .021$) as can be seen in Figure 15.

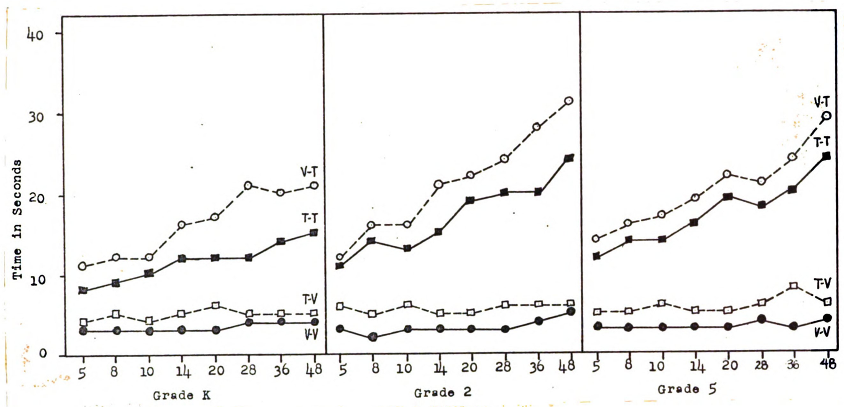
Insert Figure 15 about here

Comparison forms were generally felt longer than they were looked at across all complexity levels but significant differences were found only for the most complex forms and only among second- and fifth-graders ($p < .05$-$.01$); differences between visual and haptic exploration were not significant for the four lowest complexity levels at any grade level.

Within the haptic comparison-exploration conditions, children increased their exploration times as form complexity increased. The four most complex forms were felt longer than the four least complex forms ($p < .01$). This was a joint effect of the three grade levels; within any single grade level, only the difference between 5-sided and 48-sided forms was significant and only for second-graders ($p < .075$).

It seems reasonable that, when comparisons are explored with the same system as the standards, exploration times should be less than when they are explored with a different system. It is surprising, therefore, that exploration times for comparison forms in inter-system and intra-system conditions were not different at any grade or complexity level.

Fig. 15. Comparison form exploration time as a function of Complexity, Condition, and Grade level.



Time in Seconds
0
10
20
30
40
V-T
T-T
T-V
V-V
5
8
10
14
20
28
36
48
Grade K
Grade 2
Grade 5

The relation between comparison exploration time and correct responses seems especially difficult to predict: Exploration of comparisons that is of short duration may yield inadequate information and lead to incorrect responses. On the other hand, exploration that is of extended duration may mean that the subject cannot find those parts of the form he is looking for or it may mean that he has forgotten the standard and is looking for any part of the comparison that reminds him of it. Thus long duration exploratory behavior may also be associated with incorrect responses. Therefore, it is unclear as to what relation, it any, should exist between exploration time and correct responses for comparison forms.

The results for exploration of comparisons and for correct responses do not suggest that the two are related. Grade, Condition, and Complexity interacted to determine exploration time but complexity was unrelated to correct judgements. These inconsistencies suggest that, as with the standards, there is no direct relation between comparison exploration time and response accuracy.

c. Effects of test session. As subjects' experience in the task increased, their exploration times decreased for the comparison just as was found for the standards (Session effect, $p < .0005$). Most of the reduction in exploration time appears to have occurred within the haptic comparison presentation conditions (Session X Grade X Condition interaction, $p < .023$) but the few cell differences within this interaction preclude a clear interpretation of its meaning.

d. Effects of type of form Pair. It was expected that comparison forms would be explored for less time when they were different from standards than when they were the same and this expectation was supported by the significant Pair effect ($p < .028$). It was further expected that more complex "same" comparisons should require more lengthy exploration than less complex ones. Consistent with this expectation the Complexity X Pair interaction, shown in Figure 16 was

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Insert Figure 16 about here

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significant ($p < .001$) though the form-complexity hypothesis cannot be unequivocably supported inasmuch as both same and different pairs were affected equally by the complexity variable: Exploration times for the four least complex forms were significantly less than for the four most complex forms for both same and different pairs ($p < .01$). At no complexity level was the difference between same and different pairs significant, nor was there any consistent tendency at any complexity level for one type of pair to have been explored longer than the other. Type of Pair also interacted with Complexity level and Session ($p < .02$). This interaction seems to be of no consequence and differences between means within this interaction were not significant.

In summary, there is little evidence here of a relation between length of exploration of the comparison forms and accuracy of judgement. Type of Pair, Grade, and Condition all interact to affect judgement accuracy, but they do not interact to influence comparison-exploration times. On the other hand, both Pair type and Complexity are related to exploration times and to accuracy of judgements but not in the same way. There appears to be no direct correspondence, then

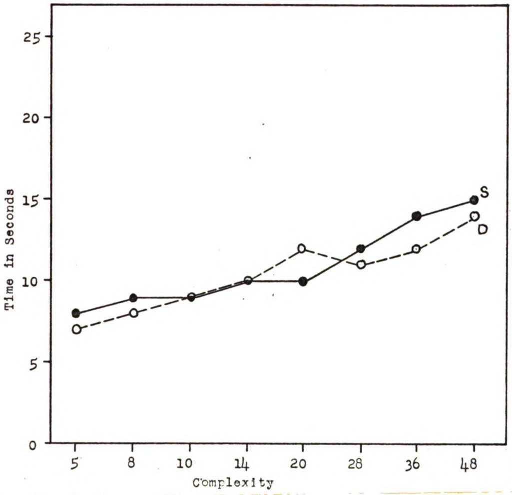

Fig. 16. Comparison form exploration time as a function of Complexity and type of Pair.

between the number of correct responses and the length of exploration of the comparison forms.

4. Within-subject variation in standard and comparison exploration times and their relation to correct responses. Although there apparently is no evidence of a consistent relation between exploration time for standards or comparisons and incidence of correct judgements by groups of children in the various conditions, it seemed possible that this relation would be found within individual subjects' scores. Since the data were not in a form suitable for computer analysis, a preliminary test of this relation was made with a stratified random sample of 24 of the 144 children, two from each condition at each grade level. Each child's average exploration time leading to correct responses was computed and compared with his average time leading to incorrect responses for both the standard and the comparison forms.

With respect to the standards, correct response times exceeded incorrect response times for 12 of the children while, for the other 12, the opposite was true and with approximately equal differences in both cases. Analyses by age and condition were equally inconclusive.

For the comparison forms, similar results obtained: 12 children were found to explore comparisons longer prior to making a correct response while 12 children explored them longer prior to making an incorrect response. There was no indication in these data of a relation for individual children, between length of exploration and performance.

It was suggested earlier that the relation between exploration time and accuracy of judgement may not be linear but instead may be curvilinear. That is, if the comparison form is explored for too short a time, the children may be judging on the basis of too little information; and if exploration of the comparison is too long, they might forget the standard because too much time has elapsed since they last examined it. Therefore the range of variation in exploration times (as measured by their standard deviation) should be greater prior to incorrect than prior to correct responses.

If anything, just the opposite seems to have been the case: exploration times were more variable prior to correct judgements than prior to incorrect judgements for 14 children, less variable for the remaining 10.

In summary, there is no evidence for a relation between exploration time and correct responses within individual subjects for either standard or comparison forms.

5. Analyses of video-tape records of children's haptic exploratory behavior and the relation between exploration and correct judgements. Haptic exploration was recorded on video-tape for the first 16 trials for all children (excepting those in the V-V condition, of course). After preliminary study of these records it seemed that children's exploration of the perimeter of the forms might change with age and be related to improvement with age in the number of correct judgements they made. Since the distinguishing characteristics of the forms used in this study were located at the perimeter of the forms a child's judgement accuracy ought to be related to his exploration of the perimeter. Specifically, the more time children spent feeling the perimeter of forms relative to the total time their hands were in contact with the forms, the better their performance ought to have been. Similarly, the more perimeter the children explored relative to the total perimeter comprising the forms, the better their

performance ought to have been. The children's behavior was scored for both these measures.

To ensure reliable scoring of the children's hand movements, two raters viewed and scored the records of twelve children, representing all ages and conditions, for sixteen trials per child. Inter-observer determinations of the children's total exploration time, total time on the perimeter, and total distance along the perimeter that was explored, were correlated.

The inter-observer Pearson Product-moment correlations were $r = .99$ for total time, $r = .98$ for time on the edge, and $r = .99$ for distance on the edge. These high correlations reflect the fact that each child's tape record was played several times at normal speed and frame-by-frame which tended to eliminate chance variation between the observers. A single observer subsequently scored the records of all other subjects in the manner just described.

Approximately 200 viewing hours were required to score the video tapes; consequently, several months lapsed between the time at which the inter-observer reliability estimates were made and the time at which the last subject's data were scored. Therefore an estimate of intra-observer reliability over this time and practice span was computed. The records for six of the twelve subjects for whom inter-observer reliability had been established were re-scored and yielded intra-observer reliability correlations of $r = .99$ for total time, and time on the edge, and for distance explored along the edge.

Four analyses of variance were performed on the scores obtained from the video-tape records--two for the exploration scores with the standard forms, two for the comparison forms. One analysis for the

standard and one for the comparison forms pertained to the percent of the total exploration time the children spent on the perimeter; the other analyses for the standards and comparisons pertained to the percent of the total perimeter comprising the forms that the children actually explored. These analyses are summarized in Tables 4, 5, 6, and 7. Scores were analyzed as a function of the children's Grade

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Insert Tables 4, 5, 6, and 7 about here

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level, presentation Condition (T-V and T-T for standards, V-T and T-T for comparisons), type of Pair (same or different), and Complexity level (the lowest four levels vs. the highest four levels). Scheffe's method was used for analyses of sub-effects.

a. Exploration time on the edge of standard forms. It was expected that younger children would spend a smaller proportion of their exploration time in contact with the perimeter of the standard forms than older children. Further, any such age difference in exploration should be especially apparent with the high complexity forms, since younger children should have more difficulty processing the information in high relative to low complexity forms than older children. These expectations were borne out by the results as can be seen in Figure 17. The proportion of time children spent exploring the perimeter

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Insert Figure 17 about here

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of the forms increased with age (Grade level effect, $p < .01$). Kindergarteners spent a lower proportion of their exploration time feeling

TABLE 4

Summary of Analysis of Variance of Percent of Exploration-time on the Perimeter of Standard Forms

Source	df	MS	F	p
Between				
Condition (C)	1	432.153	0.838	
Grade (G)	2	5083.625	9.854	.01
C X G	2	415.762	0.806	
Error	66	515.880		
Within				
Pair (P)	1	92.373	4.951	.05
C X P	1	0.186	0.010	
G X P	2	37.253	1.978	
C X G X P	2	6.390	0.342	
Error X P	66	18.657		
Complexity (L)	1	1403.464	19.348	.01
C X L	1	172.691	2.381	
G X L	2	210.018	2.895	.075
C X G X L	2	90.416	1.246	
Error X L	66	72.538		
P X L	1	1.386	0.074	
C X P X L	1	19.799	1.051	
G X P X L	2	1.754	0.093	
C X G X P X L	2	28.394	1.507	
Error X P X L	66	18.836		

TABLE 5

Summary of Analysis of Variance of Percent of

Perimeter Explored of Standard Forms

Source	df	MS	F	p
Between				
Condition (C)	1	3714.338	3.827	.075
Grade (G)	2	7796.375	8.033	.01
C X G	2	521.711	0.538	
Error	66	970.588		
Within				
Pair (P)	1	350.849	13.029	.01
C X P	1	10.276		
G X P	2	66.683	2.476	
C X G X P	2	72.016	0.382	
Error X P	66	26.927		
Complexity (L)	1	26772.379	91.670	.01
C X L	1	2.590	756.336	
G X L	2	1868.154	6.397	.01
C X G X L	2	121.127	0.415	
Error X L	66	292.053		
P X L	1	0.496	0.012	
C X P X L	1	61.978	1.457	
G X P X L	2	28.565	0.672	
C X G X P X L	2	1.217	0.029	
Error X P X L	66	42.539		

TABLE 6

Summary of Analysis of Variance of Percent of Exploration-time on the Perimeter of Comparison Forms

Source	df	MS	F	p
Between				
Condition (C)	1	100.250	0.179	
Grade (G)	2	4707.414	8.426	.01
C X G	2	115.143	0.206	
Error	66	558.687		
Within				
Pair (P)	1	1.254	0.069	
C X P	1	9.374	0.516	
G X P	2	10.822	0.927	
C X G X P	2	0.186	0.010	
Error X P	66	18.147		
Complexity (L)	1	2864.791	39.638	.01
C X L	1	18.832	0.260	
G X L	2	499.944	6.917	.01
C X G X L	2	47.533	0.658	
Error X L	66	72.273		
P X L	1	57.588	3.360	
C X P X L	1	50.977	2.974	
G X P X L	2	26.136	1.525	
C X G X P X L	2	89.320	5.212	.01
Error X P X L	66	17.139		

TABLE 7

Summary of Analysis of Variance of Percent of

Perimeter Explored of Comparison Forms

Source	*df*	*MS*	*F*	*p*
Between				
Condition (C)	1	385.944	0.255	
Grade (G)	2	7622.613	5.029	.01
C X G	2	394.146	0.260	
Error	66	1515.849		
Within				
Pair (P)	1	92.324	0.980	
C X P	1	5.014	0.053	
G X P	2	58.980	0.626	
C X G X P	2	20.469	0.217	
Error X P	66	94.160		
Complexity (L)	1	58427.117	189.328	.01
C X L	1	308.465	1.000	
G X L	2	288.141	0.934	
C X G X L	2	655.059	2.123	
Error X L	66	303.603		
P X L	1	63.402	0.809	
C X P X L	1	58.287	0.743	
G X P X L	2	260.312	3.320	.05
C X G X P X L	2	138.974	1.772	
Error X P X L	66	78.407		

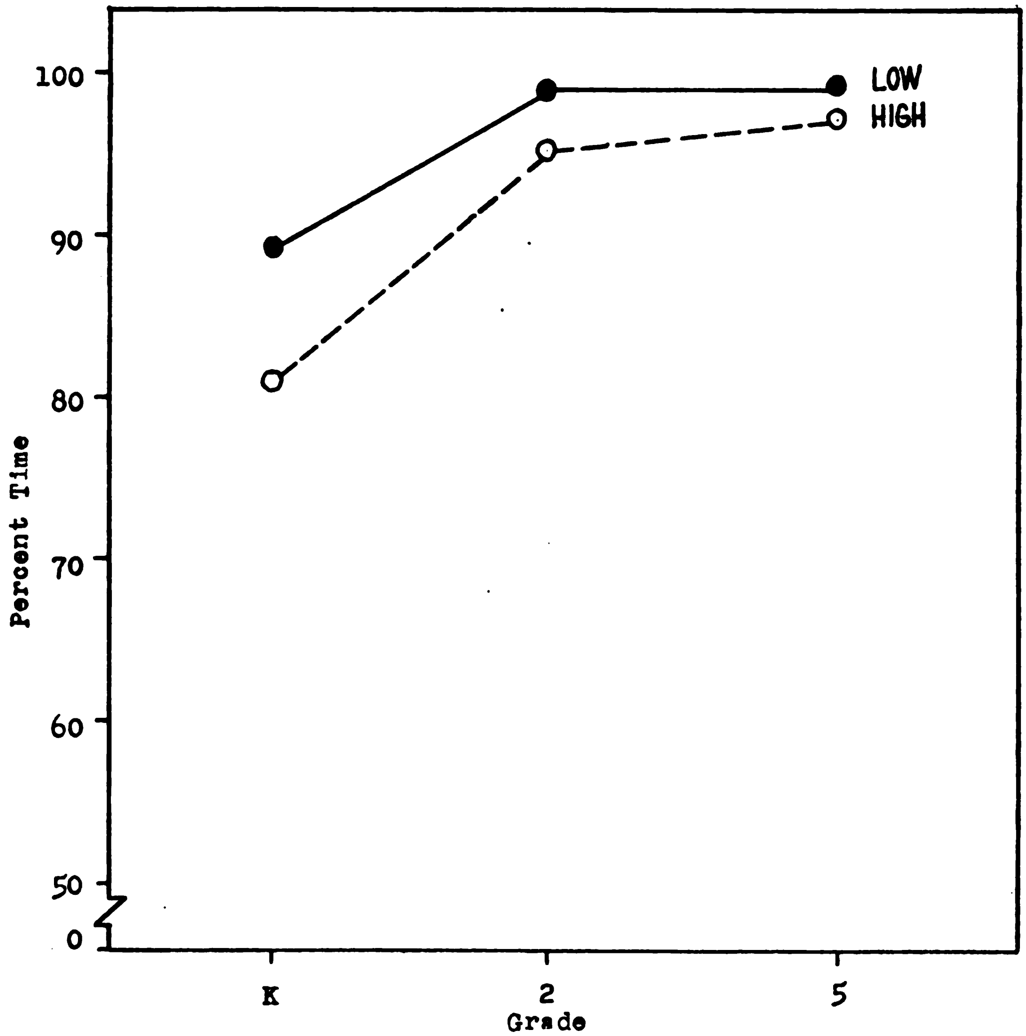

Fig. 17. Exploration time on the edge of Standard forms as a function of Grade and Complexity.

the edge of the forms than did second-graders ($\underline{p} < .01$) and fifth-graders ($\underline{p} < .01$) who did not differ from each other.

Children at all grade levels spent proportionately more time exploring the perimeter of low than high complexity forms (Complexity effect, $\underline{p} < .01$) and this difference became less pronounced as age increased (Grade X Complexity interaction, $\underline{p} < .075$, figure 17), although this is apparently due to a ceiling effect. Kindergarteners spent proportionately less time exploring the perimeter of high than low complexity forms ($\underline{p} < .01$) but second and fifth-graders explored both about equally. Second- and fifth-graders spent a greater proportion of their time feeling the perimeter of all forms than kindergarteners ($\underline{p} < .01$) but the increase with age between the kindergarteners and the second- and fifth-graders was greater for high than for low complexity forms ($\underline{p} < .10$).

Inexplicably, the type of Pair also affected the proportion of time spent exploring perimeter ($\underline{p} < .05$). Children spent a slightly greater proportion of time (1.1%) exploring the perimeter of standards among different than among same pairs. Since subjects did not know whether a same or different comparison would follow the standard they were exploring it is possible that their exploratory behavior was somehow affected by the preceding trial.

b. Proportion of total perimeter explored of standard forms. It was expected that the proportion of perimeter explored would vary with children's age and form complexity in the same way as did perimeter exploration time. Younger children should have more difficulty processing form information than older children and, consequently, should explore less perimeter. Further, this age difference should be accentuated for high relative to low complexity forms. Figure 18

Insert Figure 18 about here

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shows that the results are consistent with these expectations. Kindergarteners covered less of the forms' perimeter than did the second-graders ($p < .01$) or fifth-graders ($p < .01$) who did not differ from each other (Grade effect, $p < .01$). Furthermore, the perimeters of the more complex forms were explored less completely than were the perimeters of the less complex forms (Complexity effect, $p < .01$).

Finally, children at all ages explored a smaller proportion of the perimeter of high complexity than low complexity forms ($p <$ .05-.01), and for kindergarteners this difference was larger than for either second- or fifth-graders ($p < .01$) (Grade X Complexity interaction, $p < .01$, Figure 18). For low complexity forms there were no age differences in proportion of perimeter explored. For high complexity forms, kindergarteners explored a smaller proportion of the perimeter than did second- or fifth-graders ($p < .01$).

Paradoxically, again the perimeters of standards comprising different pairs were explored slightly more than the perimeters of standards comprising same pairs (85.8% vs 83.6%, $p < .01$).

To summarize, the older children spent a greater proportion of their time feeling the perimeter of the standard forms and explored a greater proportion of the available perimeter than did the younger children. The older children, also, were more accurate. Whether these findings imply a functional tie between exploration and

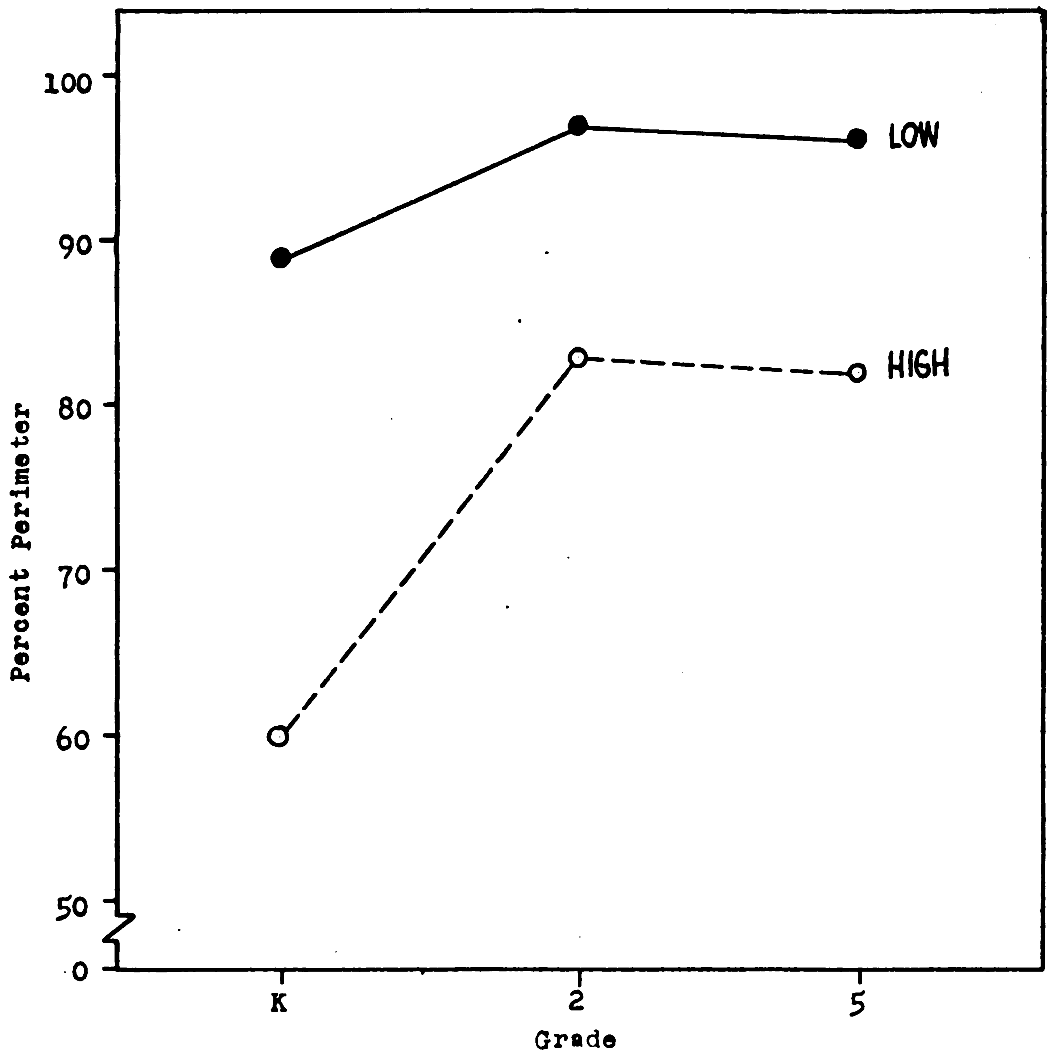

Fig. 18. Exploration of perimeter of Standard forms as a function of Grade and Complexity.

judgements is still problematic, since the relation holds for these but not other variables: Perimeter exploration varied as a joint function of Grade and Complexity while correct judgements did not.

c. Exploration time on the edge of comparison forms. Although correct responses appear to be unrelated to total exploration time for comparison forms they might nonetheless be related to the proportion of exploration time on the perimeter. The more time a child spends on the perimeter of comparisons relative to time spent in the center areas of forms, the more time he spends obtaining relevant information and the better his performance ought to be. Older children ought to spend a greater proportion of their exploration time obtaining relevant information than younger children and, consequently, age differences in proportion of time on the perimeter were expected.

Information pertaining to haptic exploration of the perimeter of comparison forms was obtained from children in the V-T and T-T conditions. The results were as expected: Generally, older children spent a greater proportion of their exploration time on the perimeter of the comparison forms than younger children (Grade effect, $p < .01$). Kindergarteners spent less time feeling the perimeter than did second- and fifth-graders ($p < .01$) who did not differ from each other.

It was also expected that complexity would influence perimeter exploration times because more information must be processed for high than for low complexity forms. The more information to be processed, the more tentative and the less thorough exploration ought to be. Since older children presumably can process more information than younger children, it was further expected that age differences would be more pronounced with high complexity than with low complexity forms. The results are consistent with these hypotheses as can be seen in Figure 19. Children at all grade levels spent

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Insert Figure 19 about here

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proportionately more time exploring the perimeter of low than high complexity comparison forms (Complexity effect, $p < .01$) and this difference diminished as age increased (Grade X Complexity interaction, $p < .01$), although this is apparently due to a ceiling effect. Kindergarteners spent proportionally less time exploring the perimeter of high than low complexity forms ($p < .01$), while second- and fifth-graders explored both about equally. The age differences in perimeter exploration time were not significant for low complexity forms, but for high complexity forms kindergarteners spent a smaller proportion of their time feeling the perimeter than did second- or fifth-graders ($p < .01$) who did not differ from each other.

The proportion of time spent on the perimeter of comparisons was unrelated to whether they were the same as or different from the standards: the Pair effect was not significant. This finding was not surprising since it should be equally important for the identification of both same and different comparisons that exploration be directed to their perimeter and not to their center areas.

d. Proportion of total perimeter explored of comparison forms. In contrast to proportion of exploration time on the perimeter, the proportion of perimeter explored ought to have depended on whether or

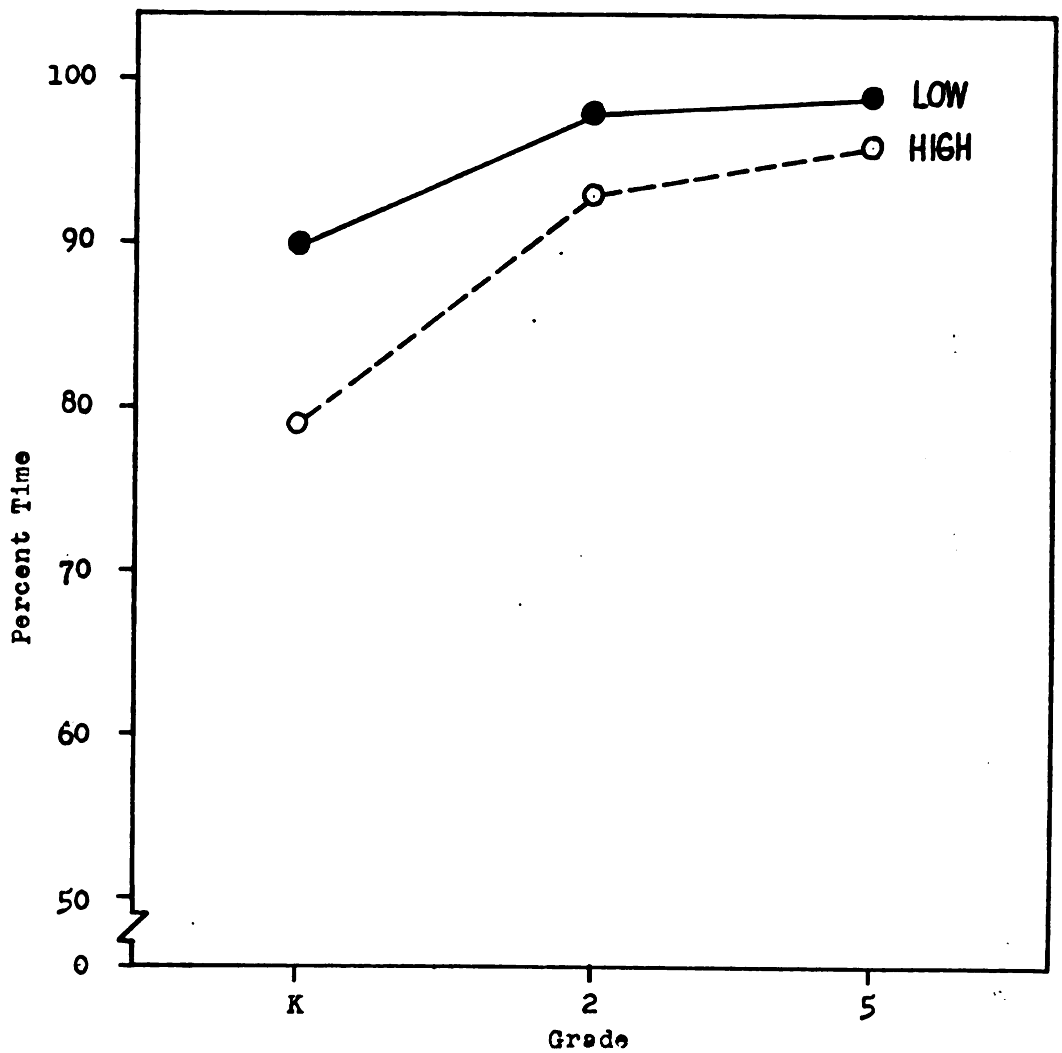

Fig. 19. Exploration time on the edge of Comparison forms as a function of Grade and Complexity level.

not the comparisons were the same as the standards. If same pairs are to be correctly identified, the comparisons ought to be as thoroughly explored as the standards; on the other hand, this need not be the case with different pairs since a correct judgement can be made as soon as any difference between them is detected. The results do not support this hypothesis, however. The only effect of Pair occurred in interaction with Grade and Complexity ($p < .05$). Within this interaction the proportion of perimeter felt of same and different pairs was about the same within each Grade and Complexity level. No other Pair differences within this interaction seem meaningful statistical significance notwithstanding.

The Grade effect was significant ($p < .01$) as might be expected although the effect seems to have been curvilinear rather than linear. Second-graders explored a greater proportion of the perimeter of comparisons than kindergarteners ($p < .05$) while the exploration of fifth-graders was in-between and not significantly different from either age group. Finally, the perimeters of less complex forms were explored more completely than the perimeters of more complex forms (Complexity effect, $p < .01$) but this complexity effect was not related to the ages of the children.

e. Analyses of differences in children's exploration of standard and comparison forms on correct versus incorrect trials. There are several ways to look at these data on children's exploratory behavior to try to determine whether some relation exists between exploration and correct responses. One way involves looking for concommitant variation in the effects of certain independent variables on both correct responses and exploratory behavior. The results of these analyses have been reported above and offer little to suggest that differences in exploration underlie correct response differences. Another way to explore this hypothesized relationship involves comparing children's exploratory behavior on correct trials with their behavior on incorrect trials. This method assumes that if exploration determines response accuracy, than a subject's exploration ought to have been different prior to correct than prior to incorrect responses. More specifically, children ought to have spent a greater proportion of their time on the perimeter of the forms and explored a greater proportion of that perimeter before making a correct response than before an incorrect response. Differences in exploratory behavior between correct and incorrect response trials were represented by difference scores and subjected to analysis of variance.

To arrive at the difference scores, the proportions of exploration time on the perimeter of forms were grouped, for each subject, according to the complexity of the forms (lowest four and highest four levels) and the type of form pair (same or different). The mean proportion of time associated with correct judgements was compared with the time associated with incorrect judgements. In other words, the difference scores refer to the proportion of exploration time on the perimeter of correct-judgement relative to incorrect-judgement trials as a function of complexity and type of pair. Difference scores were similarly derived for the proportion of perimeter the children explored.

Difference scores pertaining to haptic exploration time and distance on the perimeter of the standards (children in the T-V and T-T conditions) and comparisons (children in the V-T and T-T conditions) were analyzed by analysis of variance. These analyses are summarized in Tables 8, 9, 10, and 11. The significance of

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Insert Tables 8 and 9 about here

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differences between means within significant effects was tested by Scheffe's method.

1. Evidence for differential exploration of standard forms. The difference-score analysis of time on the perimeter of standard forms showed significant effects Grade ($p < .01$), Condition ($p < .01$), and Complexity ($p < .05$), and no interactions. Generally, children spent a greater proportion of their time feeling the perimeter prior to correct than prior to incorrect responses. This difference was greater for T-T than for T-V children, greater for second- and fifth-graders (who didn't differ from each other) than for kindergarteners ($p < .05$, $p < .01$, respectively), and greater for low complexity than for high complexity forms.

The difference-score analysis of the proportion of the perimeter of the standards that the children felt exactly paralleled the results for time: Main effects of Condition ($p < .05$), Grade ($p < .01$), and Complexity ($p < .05$) were significant and interactions were not. Again it is generally true that correct judgements were preceded by more thorough exploration of the perimeter than were incorrect judgements. This difference was greater for T-T than for T-V children, greater for second- and fifth-graders (who did not differ) than for kindergarteners ($p < .10$, $p < .01$, respectively), and greater for low complexity than for high complexity forms.

TABLE 8

Summary of Analysis of Variance of Difference-Scores for Time Exploring the Perimeter of Standard

Source	df	MS	F	p
Between				
Condition (C)	1	14078.816	7.303	<.01
Grade (G)	2	17795.141	9.231	<.01
C X G	2	2373.533	1.231	
Error	66	1927.774		
Within				
Pair (P)	1	54.088	0.008	
C X P	1	6154.453	0.905	
G X P	2	1585.628	0.233	
C X G X P	2	2610.830	0.384	
Error X P	66	6799.195		
Complexity (L)	1	7795.941	4.628	<.05
C X L	1	24.922	0.015	
G X L	2	1997.440	1.186	
C X G X L	2	14.422	0.008	
Error X L	66	1684.436		
P X L	1	12.316	0.005	
C X P X L	1	9102.930	3.845	<.10
G X P X L	2	1911.471	0.807	
C X G X P X L	2	1737.959	0.734	
Error X P X L	66	2367.232		

TABLE 9

Summary of Analysis of Variance of Difference-Scores for the Amount of Perimeter Explored of Standards

Source	df	MS	F	p
Between				
Condition (C)	1	10840.504	5.104	<.05
Grade (G)	2	13822.525	6.507	<.01
C X G	2	2211.014	1.041	
Error	66	2124.118		
Within				
Pair (P)	1	417.507	0.078	
C X P	1	223.997	0.042	
G X P	2	627.065	0.117	
C X G X P	2	2429.441	0.455	
Error X P	66	5339.836		
Complexity (L)	1	6065.270	4.207	<.05
C X L	1	498.320	0.346	
G X L	2	2426.443	1.683	
C X G X L	2	130.148	0.090	
Error X L	66	1441.725		
P X L	1	129.106	0.054	
C X P X L	1	531.800	0.221	
G X P X L	2	1169.369	0.485	
C X G X P X L	2	2545.322	1.055	
Error X P X L	66	2411.540		

These analyses show only that the magnitude of exploration differences is related to Grade, form complexity and presentation condition. They do not tell us whether the exploratory behavior leading to correct judgements is significantly different from exploration leading to incorrect judgements. If exploration of the perimeter is more thorough, as reflected in time and distance measures, prior to correct than prior to incorrect responses, then mean difference scores should be positive and significantly greater than zero.

To test for a significant departure of a mean difference score from zero, confidence intervals were set up around zero for each significant effect. The fact that all mean differences within all significant effects were positive indicates that the exploration leading to correct judgements exceeded that leading to incorrect judgements. No mean difference within any significant effect was *significantly* greater than zero, however.

Insert Tables 10 and 11 about here

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2. *Evidence for differential exploration of comparison forms*. A difference-score analysis was carried out with the comparison forms in the same manner as for the standards. The following results pertain to analyses for time and distance on the perimeter of comparison forms and can be seen to parallel the results for the standards.

The difference-score analysis of the proportion of *time* children explored the perimeter of comparison forms showed a significant effect of *Grade* ($p < .01$); The proportion of time feeling the perimeter prior to correct judgements exceeded that prior to incorrect judgements

TABLE 10

Summary of Analysis of Variance of Difference-Scores for Time Exploring the Edge of Comparisons

Source	df	MS	F	p
Between				
Condition (C)	1	180.046	.069	
Grade (G)	2	20411.969	7.790	<.01
C X G	2	1164.727	0.444	
Error	66	2620.429		
Within				
Pair (P)	1	7793.074	1.831	
C X P	1	15782.656	3.708	<.10
G X P	2	4425.430	1.040	
C X G X P	2	4845.852	1.139	
Error X P	66	4255.988		
Complexity (L)	1	14687.254	8.740	<.01
C X L	1	4502.266	2.679	
G X L	2	2064.736	1.550	
C X G X L	2	378.684	0.225	
Error X L	66	1680.553		
P X L	1	1246.477	0.483	
C X P X L	1	1611.781	0.624	
G X P X L	2	4480.523	1.735	
C X G X P X L	2	242.643	0.094	
Error X P X L	66	2582.726		

TABLE 11

Summary of Analysis of Variance of Difference-scores for the Amount of Perimeter Explored of Comparisons

Source	df	DM	F	p
Between				
Condition (C)	1	24.208	0.012	
Grade (G)	2	11320.613	5.695	<.01
C X G	2	498.822	0.251	
Error	66	1987.877		
Within				
Pair (P)	1	2695.967	.832	
C X P	1	13058.348	4.031	<.05
G X P	2	3815.193	1.178	
C X G X P	2	1682.148	0.519	
Error X P	66	3239.424		
Complexity (L)	1	24190.066	17.472	<.01
C X L	1	2074.473	1.498	
G X L	2	2277.717	1.645	
C X G X L	2	182.680	0.132	
Error X L	66	1384.530		
P X L	1	40.465	0.022	
C X P X L	1	5118.856	2.761	
G X P X L	2	3592.258	1.937	
C X G X P X L	2	70.266	0.038	
Error X P X L	66	1854.128		

by a significantly greater margin for second- and fifth-graders than for kindergarteners ($p < .05$ and $p < .01$, respectively). The second- and fifth-graders were not significantly different from each other.

The proportion of time feeling the edge prior to correct relative to incorrect judgements was greater for low than for high complexity forms (Complexity effect, $p < .05$). In other words, differential exploration time is a more important factor in judgements of low than of high complexity forms.

The results of the analysis of the proportion of the distance along the perimeter the children felt paralleled the results for time on the perimeter. The significant Grade effect ($p < .01$) shows that fifth- and second-graders felt a greater proportion of the perimeter of comparison forms prior to correct judgements than prior to incorrect judgements by a significantly greater margin than kindergarteners ($p < .05$); second- and fifth-graders did not differ from each other.

The extent to which the proportion of perimeters explored of comparison forms prior to correct judgements exceeded that for incorrect judgements was greater for low complexity than for high complexity forms (Complexity effect, $p < .01$). In other words, differential exploration of the amount of perimeter, like length of exploration time, is a more important factor in judgements of low than of high complexity forms.

The interaction of type of Pair and Condition was significant ($p < .05$) but no differences between means within this interaction were significant and no explanation of this effect can be offered.

Despite the statistical significance of variation in the magnitude of difference scores for comparison exploration as a function of grade and complexity, none of these mean differences was large enough to be significantly greater than zero. In other words, for the comparisons as for the standards, there is a clear tendency for older children to explore forms differently prior to correct and incorrect judgements and for exploration differences to be associated with the identification of less complex forms but these differences are not large.

To summarize these findings for both standard and comparison forms, the adquacy of exploration, as measured by time and distance on the perimeter, tends to be more closely related to response accuracy for older than for younger children; younger children's performance appears to be unrelated to exploratory behavior. Also, differences in exploration tend to be more closely related to response accuracy for simple than for complex forms: correct versus incorrect judgements of complex forms seem not to result from differences in exploratory behavior. Finally, differential exploration of standards tends to be more closely related to response accuracy for children in the T-T than in the T-V condition: factors other than differential exploration apparently underlie variation in correct judgements in the T-V condition. With respect to all of these findings differences in response accuracy were not associated with large differences in exploration but it is important to note that, in all groups, more and not less exploration was associated with correct than with incorrect responses.

f. Analysis of exploration of specific parts of standard and comparison forms. The analyses of exploratory behavior presented thus far have pertained to measures of thoroughness of exploration. There are other aspects of exploratory behavior that were not explicitly examined in these analyses, however, and that deserve attention. One aspect of exploratory behavior has to do with whether or not children can direct their exploration to areas of comparisons that are comparable to areas explored on the standards. Performance ought to be better when the perimeter explored on comparison forms is the same as that explored on the standards than when it is different. Age differences ought also to be found here because older children should be better than younger children at locating areas on comparisons that are identical to areas explored on the standards. Complexity effects might be expected to operate here also since it should be more difficult to locate identical parts of complex than of simple forms. Finally, any complexity effects that obtain ought to be more pronounced for younger than for older children.

To test these hypotheses, the video-tape records of haptic exploration of same pairs by children in the T-T condition were scored for the proportion of perimeter explored on the standards that was subsequently explored on the comparisons. Thus, eight "overlap" scores were obtained for each of the twelve subjects at each grade level. These scores were subjected to an analysis of variance as a function of Grade and form Complexity.

The results of this analysis, which is summarized in Table 12,

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Insert Table 12 about here

TABLE 12

Summary of Analysis of Variance of "Overlap"

of Perimeter Exploration

Source	*df*	*MS*	*F*	*p*
Between				
Grade (G)	2	2183.617	2.027	
Error	33	1077.246		
Within				
Complexity (L)	7	3535.339	9.709	$\leq .01$
G X L	14	515.582	1.416	
Error X L	231	364.120		

revealed a non-significant Grade effect ($0.75 < p > .10$) and reflect the fact that there was no tendency for theamount of overlap to increase with age. The Complexity effect was significant ($p < .01$) showing that there was more overlap with simple than with complex forms but this effect was not related to grade level.

An additional analysis was conducted where, for each subject, percent of overlap was compared on correct and incorrect trials as a function of Grade level. This analysis is summarized in Table 13. The results show that, in general, there was more overlapping exploration on correct than on incorrect trials and also that overlap differences were larger for older than for younger children. While differences between means are all in the right direction none of the effects was significant at an acceptable level of significance.

Insert Table 13 about here

While it seems reasonable that performance will be lower to the extent that subjects explore less of those areas on comparisons than they explored on standards, it also seems reasonable that performance should be lower when subjects explore parts of a comparison that they did not explore on a standard. On such occasions as these, they are picking up information that is irrelevant to the discrimination, noise in addition to signal so-to-speak, and this pick-up of irrelevant information might be expected to impair performance. Specifically, it seems likely that younger children should pick up more irrelevant information than older children. Also, more irrelevant information ought to be obtained from high than from low complexity forms, especially by the younger children.

TABLE 13

Summary of Analysis of Variance of Overlap of Perimeter Exploration Associated with Correct Responses

Source	df	MS	F	p
Between				
Grade (A)	2	890.500	1.265	
Error	33	703.888		
Within				
Correct-Incorrect (C)	1	1650.237	2.443	.10
A X C	2	1236.985	2.580	
Error X C	33	479.350		

To test these hypotheses, the video-tape records of subjects in the T-T condition who explored same pairs of forms were scored for the proportion of comparison exploration that duplicated the exploration of the standard. In other words, the proportion of comparison exploration that was relevant to the standard was recorded; an analysis of variance was conducted on these proportion scores as a function of Grade and form Complexity. This analysis is summarized in Table 14.

The results of this analysis showed that the Grade effect was significant ($p < .05$); Older children obtained less irrelevant information than did younger children; differences between grade levels were not large enough to be significant however. The Complexity effect ($p < .01$) showed that less irrelevant information was detected on the low than on the high complexity forms; older children were less influenced by form complexity than were younger children who tended to pick up more irrelevant information on high than on low complexity forms (Grade X Complexity interaction, $p < .01$). These findings suggest that younger children detect more irrelevant information because they are unable to restrict their exploration to those form parts which yield only relevant information. Unfortunately, the acceptability of this conclusion is diminished by the fact that, since older children explored forms, especially high complexity ones, more thoroughly than younger children, there was less information on the comparisons that could be irrelevant for them. Thus the possibility that an important difference between kindergarten and fifth-grade children lies in their relative ability to detect only relevant information in a haptic discrimination cannot be decided by these data.

Insert Table 14 about here

The proportion of comparison exploration that yielded relevant information was compared on correct and incorrect response trials for individual subjects. An analysis of variance for exploration as a function of Grade level and Correct vs Incorrect responses was conducted (see Table 15) and showed that less irrelevant information was obtained prior to correct than prior to incorrect responses ($p < .05$). There was also a tendency for differences in the amount of irrelevant information detected on correct versus incorrect trials to be greater for older than for younger children although this tendency was only marginally significant (Grade X Correct-Incorrect interaction, $p < .10$). Thus, younger children tend to pick up more irrelevant information than older children, especially with high complexity forms, but differences in the amount of irrelevant information are related to correct responses only for older and not for younger children. In other words, fifth-graders do not pick up much irrelevant information, but what they do pick up impairs their performance. Kindergarteners, on the other hand, pick up much irrelevant information but their performance is no more impaired when they pick up more irrelevant information than when they pick up less.

Insert Table 15 about here

TABLE 14

Summary of Analysis of Variance of the Percent

of Irrelevant Perimeter Exploration

Source	df	MS	F	p
Between				
Grade (A)	2	3248.764	4.771	<.05
Error	33	680.977		
Within				
Complexity (L)	7	933.807	4.607	<.01
A X L	14	561.198	2.769	<.01
Error X L	231	202.684		

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TABLE 15

Summary of Analysis of Variance of the Percent of Irrelevant Perimeter Explored Associated with Correct Responses

Source	df	MS	F	p
Between				
Grade (A)	2	425.054	.793	
Error	33	536.265		
Within				
Correct-Incorrect (C)	1	2763.943	5.434	<.05
A X C	2	1449.658	2,850	
Error X C	33	508.678		

To summarize these results pertaining to haptic exploration of specific parts of forms, there appear to be important differences between kindergarteners and fifth-graders in their exploratory behavior but only for the older children is variation in exploratory behavior associated with variation in response accuracy.

DISCUSSION

The results of this research bear on two fundamental questions: First, "What process underlies inter-system perception?" and, second, "What factors underlie developmental change in inter-system perception between the ages of kindergarten and fifth-grade?" Essentially three views are held currently as to the processes underlying inter-system perception and the present findings can be related to them. Birch and Lefford (1963) have said that inter-system perception requires the development of neurological "linkages" between the perceptual systems. A second view--"the traditional sensation-based view"--holds that the association of "input" from the different systems is required for inter-system perception.

Given these first two views and a successive discrimination task involving vision and touch, one would expect the performance of subjects in the counterbalanced inter-system conditions (T-V and V-T) to be the same since the same associations or linkages are involved in both. The present research shows that V-T performance was better than T-V performance. To explain these findings it is necessary to suppose that another process, such as memory, may be involved in the task and may be involved differently in the two conditions. Specifically, ch

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children may not remember things they have felt as well as they can remember things they have looked at. This is only an hypothesis and deserves experimental test.

Differences in performance were also found between inter-system and intra-system conditions: V-V and T-T performance was better than V-T and T-V performance respectively. Since these differences arise between conditions in which the standards were explored with the same system, they cannot be attributed to differential memory for things looked at and felt. Instead it seems necessary to make further assumptions about the relative strength of associations or linkages in intra-system and inter-system tasks. These assumptions have not as yet been outlined by the adherents of these two views. In summary, the associationistic or linkages views of perception can be used to explain these results only when supplemented by other assumptions whose validity remains untested.

A third view of inter-system perception, outlined by the Gibsons (1966, 1969) seems to handle the present findings somewhat more easily. According to their view, a perceptual system detects information in stimulation some of which can also be detected by other systems. It is the existence of trans-system information that makes inter-system perception possible. Inter-system perception thus depends on the availability of information in stimulation that is relevant for the systems used in a particular perceptual task and the ability of the organism to detect that information. In the present study, it is clear that the forms used as discriminanda provided information that was relevant to both the visual and haptic sy

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systems, although the subjects were better able to detect form information visually than haptically.

The ability to detect information in a perceptual task depends on the natural sensitivity of that system to the relevant information in stimulation and on the subject's practice at detecting that information. There is no reason to assume equal sensitivity or equal practice at visual and haptic detection of form information so the fact that visual performance exceeded haptic is not surprising. The opposite results might have obtained had targets varying in texture and not form been used if children's natural sensitivity for and practice at detecting variation in texture favors touch more than vision.

In inter-system conditions (T-V and V-T) where both systems are used, performance ought to depend especially on the system used to explore the standards since, in a successive discrimination task, adequate perception of and memory for the standard is essential in order for the subject to be able to relate the comparison to it. Since visual perception was better than haptic in intra-system tasks it seems likely that performance should be better in an inter-system task when standards are explored visually than when they are explored haptically. Therefore, it might be expected that V-T would exceed T-V performance as was found in the present research.

The finding that performance was worse in inter-system than in intra-system tasks can also be explained in light of Gibson's theory. Since trans-system information is a subset of all the information that a perceptual system can detect it seems reasonable that trans-system information should be harder to detect than information relevant to ju

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to just one system alone. Therefore, it is not surprising that V-V and T-T performance was better than V-T and T-V performance respectively. The hypothesis that trans-system information is harder to detect than is information relevant to a single perceptual system is also supported by the results for exploration time: Standards were explored longer when the comparisons were to be subsequently presented in another system than when they were not.

In summary, Gibson's theory predicts and the results show that performance in intra-system and inter-system tasks depends on the relative efficiency of the perceptual systems used, especially for exploring the standards, and whether or not it is necessary for the subject to use another system to identify the comparison as the same as or different from the standard.

What factors underlie improvement with age in inter-system perception between kindergarten and fifth-grade? One hypothesis holds that associations (linkages) are built up between the sense data deriving from each perceptual system. The findings reported here show that developmental change tends to be different in the T-V and V-T conditions, though identical change would be expected since the same associations (linkages) ought to be involved in both tasks. In conjunction with the finding that the levels of performance in the two conditions are different, it can be concluded that developmental change in inter-system tasks is unlikely to depend in any major way on the development of associations between the systems.

A second hypothesis holds that improvement in inter-system perception simply reflects improvement in one or both systems involved in the task. In the present study, improvement in visual perception

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was slight and not significant so the improvement found in the V-T condition cannot be attributed simply to better visual performance. Improvement was significant in the T-T condition, however, and so V-T improvement might be attributed to improvement in haptic perception. Two factors militate against this conclusion: First, the rate of improvement in these two conditions was significantly different; second, there ought also to have been significant improvement in the T-V task if improvement in haptic perception is pervasive.

According to Gibson's theory, one would expect improvement with age in trans-system tasks as a function of children's practice at detecting information in one system that is relevant to another. One might expect different rates of development in V-T and T-V conditions if practice at detecting information visually that is relevant to touch is not the same as practice detecting information haptically that is relevant to vision. Given that the levels of performance and developmental change in the V-V and T-T conditions are different it is not surprising that there are also differences in developmental change in the T-V and V-T conditions. The present research does not provide conclusive evidence bearing on the hypothesis that developmental change in inter-system tasks reflects improvement in the ability to detect trans-system information. A transfer-of-training study involving practice at detecting trans-system information would be more conclusive.

Another potential basis for age differences in performance in perceptual tasks can be found in the greater "information processing" capacity of older relative to younger children. In the present study it was thought that older children should perform better than younger children, especially with high complexity forms, because of their greater capacity for assimilating and retaining information. In contrast to this prediction, the results showed no relation between age and complexity for correct responses. Although this finding may suggest that age differences in processing bear no relation to age differences in correct responses, it is also possible that the forms used in this task did not require different amounts of processing for correct identification of them despite the variation in their complexity.

Random shapes have been used in many different studies because, presumably, more complex shapes require more processing than do less complex shapes. In those studies, subjects have been asked to look at, associate to, state a preference for, and identify forms varying in complexity. Despite their use of identical form parameters, the results have varied depending on the particular task. It seems incorrect, therefore, to presume that differential information processing is involved in all tasks that make use of forms that vary in perimeter. Whatever information-processing is involved in a task depends on the task itself and not on the fact that forms varying in complexity are used.

It seems entirely possible that the present task made little if any demand on differences in information-processing ability among children of the different ages tested and, as a consequence, processing differences were not related to response accuracy. This possibility exists because the forms used in this study, when they were the same, had all aspects identical, yet had no aspects in common when they were different. The forms were not identical in some ways and

different in others. Therefore, it was necessary to process only parts of forms even when "same" pairs were presented.

Further evidence that the forms used in this study placed little demand on subjects' information processing ability can be found in the results for correct responses as a function of whether the form pairs were the same or different. Same pairs ought to have demanded more information-processing than different pairs and should have been more difficult to correctly identify especially for younger children and especially for forms of high complexity. Although the results show that improvement with age in correct responses was greater for same pairs than for different pairs, different pairs were not easier to identify than same pairs at any age level and were not related in any consistent way to form complexity and age. It seems likely, then, that the current findings do not bear on the question of the importance of information processing in perceptual development because differential processing apparently was not required of the subjects.

Might age-differences in performance be attributed to differences in exploratory behavior? Gibson's theory is built on the notion that performance in a perceptual task depends on the ability of the subject to detect the information distinguishing the targets. Developmental change in performance is thus seen to reflect change with age in the ability to detect information and, since information detection is seen by Gibson to involve the active use of perceptual systems, exploratory behavior and developmental change in exploratory behavior ought also to be related to performance. Past research too, notably that of Vurpillot (1968), has implicated the importance of exploration in age differences in performance in perceptual tasks.

In the present study several measures were made of exploratory behavior. These measures consisted of total exploration time, perimeter exploration time, and the proportion of perimeter explored of the standard and comparison forms. Older children's haptic exploration was generally more "thorough" than was the exploration of younger children, especially with the more complex forms. From these observations one would expect older children to have made fewer errors than younger ones especially in the T-T and T-V conditions and especially with the high complexity forms. Correct responses, while associated with age and condition, were not associated with complexity, however.

It then becomes important to consider why there are age differences in exploration if these differences do not relate to correct response differences. It seems possible that fifth-graders are generally more thorough in their exploration than kindergarteners despite the specific demands made of them by the task. Therefore, kindergarteners may have explored forms only to a certain extent which, because of the characteristics of the forms, was sufficient to identify even the most complex ones. Older children may have explored forms more thoroughly perhaps as a general strategy and thus detected more information than was really necessary for them to be able to respond correctly.

Although the differences between younger and older children in the "thoroughness" with which they explore were not related to correct response differences, other differences in their exploratory behavior looked likely to be of some importance. One's impression gained from viewing the video-tape records was that older children explored very systematically, feeling parts that were adjacent to one another. Younger children, on the other hand, tended to explore non-adjacent parts in what appeared to be a very unsystematic way. Therefore, it seemed likely that there might be age differences in the extent to which identical parts would be explored on comparisons that were first explored on the standards. The analyses did not bear out this hypothesis.

Other evidence suggesting that age differences in correct responses relates to exploration differences comes from the analysis of the amount of irrelevant information that children detect. Unfortunately, the importance of the finding that kindergarteners detect more irrelevant information than fifth-graders is diminished by the fact that the more thorough exploration of the fifth-graders markedly reduced the possibility that as much information deriving from their exploration could be irrelevant. The only way to adequately test this hypothesis would be to match subjects of different ages for the amount of the perimeter they explore of the standards and then to look for differences in the amount of irrelevant information they detect on the comparisons. The present data are too limited in quantity to permit this kind of analysis.

It appears, then, that age differences in correct responses are unrelated to differences in exploration and it is tempting to draw the larger conclusion that variation in a child's exploratory behavior is not related to his response accuracy. These data show convincingly, however, that this conclusion is only valid for kindergarteners and i

not for fifth-graders. In order to offer a parsimonious, though admittedly post-hoc, explanation of these findings it is necessary to distinguish between information about form obtained by exploration and information used.

Correct identification of forms requires not only that a subject detect information about them but also that he be able to make use of the information he has detected. Since response accuracy is related to exploratory behavior for older children it appears that incorrect responses can be attributed to faulty information detection. On the other hand, for younger children, differences in exploration are not so important for determining whether or not they will be correct. Instead it seems that their use of the information they detect may determine their accuracy. The ability to use information detected may be related to, or the same as, the ability to remember information detected. Therefore, an important difference between the younger and older children in this study may have been their relative ability to remember the information they detected about the forms.

It seems possible that memory may have been an important part of the present task, since the forms to be discriminated were presented successively. Therefore it is not unreasonable that differences between kindergarteners and fifth-graders in their ability to remember form may have produced these results. To test the hypothesis that age differences in the ability to remember the information detected is related to age differences in correct responses the present study might be replicated and the time interval between successive form presentations varied. The results of the present study make this hypothesis very much worth testing and, if such results are positive, we can then ask why it is that kindergarten-age children can remember some forms and not others.

APPENDICES

APPENDIX A

The forms used in this research were generated with a matrix of 100 X 100 squares on 8 squares to-the-inch graph paper. Pairs of numbers between 0 and 100 were taken from a table of random numbers and used as coordinates for plotting points within the matrix. The number of pairs drawn for any particular form corresponded to the number of sides the form was to have with the restriction that any two plotted points had to be at least three squares apart. The matrix was then bisected vertically and horizontally and the point upper most and nearest to the vertical axis in the upper right quadrant was taken as the starting point. A line was then drawn from this point to the next lowest point in the quadrant, and so on through the lower right quadrant. After the lowest point in the right lower quadrant was reached, the next point to which a line was drawn was the lowest point in the lower left quadrant nearest the vertical axis. Lines were then drawn to successive points moving in an upward direction through the upper left quadrant. Finally, the uppermost point in the upper left quadrant was connected by a line to the starting point.[12]

This principle was used to generate 9 forms at each of 8 complexity levels (5, 8, 10, 14, 20, 28, 36, and 48 sides). The perimeter of each form was then measured and the mean perimeter for each complexity level was calculated. The mean perimeters for the forms at

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[12] If three points fell along a straight line one of them was moved 3 squares, the point and the direction in which it was moved being such as to maximize irregularity in the contour of the form.

the successive complexity levels were found to differ by about 25%. Then the perimeter of the forms at each complexity level were altered by changing the position of as few points as possible so that all forms at each complexity level came to have the same perimeter. Thus, the perimeter increase from level to level was 25%. An exception to this rule was made for the intervals between the 8- and 10- and 10- and 14-sided forms where the increase was 12.5%.

APPENDIX B

Four blocks of form pairs were generated with each block containing one pair of forms at each of the eight levels of variability. The ordering of the eight complexity levels in each block was only quasi-random since some constraints were thought to be necessary: The first form pair of a block could not be a 36- or a 48-sided one since it seemed undesirable to present what was expected to be a maximally difficult pair on the first trial. Also, care was taken that, within each block, the first four and the last four trials should contain both low and high variability forms. Finally, care was taken that, when blocks were placed in succession, the last trial of one and the first of a succeeding block did not call for presenting forms of the same level of variability.

Determination of whether a particular pair was to consist of same or different forms was also determined quasi-randomly. The constraints imposed here were that the first two trials in each block must consist of one same and one different pair of forms and that no more than three successive trials could be comprised of the same type of form pair (same or different). Four same and four different pairs were presented in each block of eight trials.

The trial blocks produced were these:

Block 1		Block 2		Block 3		Block 4	
Var. level	S-D	Var. level	S-D	Var. level	S-D	Var. level	S-D
20	S	10	D	8	D	14	S
36	D	48	S	20	S	28	D
14	D	8	S	14	D	36	D
10	S	20	D	36	S	8	S
28	S	5	D	10	S	20	D
8	D	28	D	48	D	48	S
48	D	36	S	5	D	5	S
5	S	14	S	28	S	10	D

The orders in which the four blocks were presented were: Order I, Blocks 1,2,3, and 4 and, for Order II, Blocks 4,3,2, and 1.

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