The Development of Word Perception and Problem Solving Strategies

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This study examines the nature of children's word perception, focusing on both the developmental changes in the perceptual process itself (in terms of the ability to decenter) and the role these changes play in determining choice of strategy in a problem solving situation (anagrams). It also demonstrates the importance of individual differences (in spatial ability) as a source of information about developmental processes and changes in perception and cognition. Eight, eleven, and fourteen year-olds solved anagrams of various types and took several aptitude tests. The results give support to Piaget's formulation of perceptual development and demonstrate the role of both perceptual development and individual aptitude differences in children's problem solving strategies.

Many theories of the development of perception present a picture of the young child's perceptions being global and diffuse at first, and then becoming more differentiated as he grows older. More specifically, Piaget and Morf (1958) see perceptual development as follows: the young child's perceptions are "centered", i.e., they are static (limited to the dominant perceptual organization) and are governed by field effects (Gestalt-like principles such as good form, closure, and contrast). With increasing age the development of perceptual regulations (internalized sensori-motor acts) leads to a higher-order perceptual system which allows the child to break down a configuration and to rearrange the component elements. This development results in the older child's perception being what Piaget and Morf call "decentered."

One purpose of this study is to test the validity of this theory of perceptual development when it is applied to the perception of verbal symbols and to investigate developmental changes in word perception in terms of the ability (or lack thereof) to break down a word perceptually into its component parts. It should be noted that "word perception" is an ambiguous term and may include a number of different

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processes. First, it necessarily involves perception in the classical sense: awareness of the stimulus; i.e., perception of the letters per se. Second, word perception may include recognition of the phoneme correspondences to the perceived letters or groups of letters. Third, it may also require recognition of referential meaning. It is the first process—the perception of letters and groups of letters per se—which is of primary interest in this study; it investigates the child's ability to perceive the parts (individual letters) of a whole (a word), an essential process when learning to read or when sounding out new words.

A second purpose of this research is to examine developmental changes in strategies used to solve problems involving word perception and to show how these changes are intimately related to level of perceptual development. In addition to depending on developmental perceptual level, choice of strategy in problem solving that requires word perception (such as breaking down the word into component parts vs. whole word perception) may also depend directly upon aptitudes such as spatial ability. The success of a strategy that requires rearrangement of the component letters is a function of the ability to manipulate and rearrange figures internally. In other words, both a child's developmental perceptual level (where he is on the centering-decentering continuum) *and* his spatial ability will determine not only his *choice* of problem solving strategy, but also his *success* with his chosen strategy. Interactions of developmental perceptual level (as described by Piaget) with abilities or aptitudes are probably more accurate predictors of the nature of a given child's problem solving strategies than either developmental level or aptitude alone.

In addition to the theoretical interest of this question, a child's ability to break down a word perceptually into its component parts (letters or subgroups of letters) has important implications for reading instruction, especially when considered in terms of aptitude-treatment interactions. The latter notion suggests that children high in a given aptitude or ability (e.g., decentration, spatial ability, etc.) might do best under one type of instruction (e.g., phonetics reading instruction), while those low in that ability might do best under another (e.g., whole-word approach to reading instruction). In addition, those low in a given aptitude or ability might profit from practice or training in using that ability. It would be useful to broaden our conceptual framework for studying word perception by supplementing a general theory of perceptual development like Piaget's with important information about individual differences.

The anagram task, as yet only rarely used in developmental research (Beilin, 1967; Elkind, Horn, and Schneider, 1965; Stevenson and Odom, 1965; Stevenson, Klein, Hale, and Miller, 1968), seems particularly appropriate for the study of both word perception processes and problem solving strategies. Word perception is obviously an essential part of the anagram task, and different strategies used by subjects are relatively easy to identify by varying parameters of the task such as anagram type (the set of letters presented to the subject may be either in word form or in nonsense form), frequency of the solution-word, letter transition probabilities of the solution-word, etc.

The perceptual processes proposed by Piaget's theory of perceptual development should result in age differences in strategies used in the anagram task. The young child has very little ability, and therefore very little tendency, to rearrange the letters of an anagram in attempting to solve the problem. Rather, he perceives the anagram as whole, and then proceeds to search his word store for words whose letters match those in the anagram before him. While our present knowledge of memory and search processes does not allow us to be very specific about how the search is carried out, we would suspect on the basis of children's verbal associations, that words similar in sound to the word or nonsense anagram would be called up for comparison. However, the main suggestion here is that the young child does *not* tend to rearrange the letters of an anagram in trying to solve the problem, but rather uses a whole-word strategy in which he produces words from memory and checks to see if they match the anagram letters.

On the other hand, the older child, as a result of both his increasingly decentered perception and his growing experience with and knowledge of the characteristics of his language, tends more to break the anagram down into its component parts and to rearrange those letters or syllables into likely sequences. The evidence for this strategy in adults has been presented elsewhere (Furby, 1968). It is quite clear why the older child chooses to use a new strategy which is now at his disposal—it is much more effective. Not only is the whole-word method ineffective for him since his word associations are likely to be on the basis of meaning (at least when the anagram is a word), but furthermore, his knowledge of letter transition probabilities is extremely useful in ruling out a large percentage of the possible letter rearrangements (Ronning, 1965). Thus, a search process based on letter rearrangement turns out to be more efficient in general than one based on calling up whole words.

Individual aptitude differences should play a role in determining strategies used in solving anagrams. It has been demonstrated that spatial visualization ability is important in solving complex problems in general (Frandsen and Holder, 1969) and in solving anagrams in particular (Gavurin, 1967). Thus, with the above picture of developmental changes in perception in mind, it follows that spatial ability should be more important as a determinant of the performance of older children than of the performance of younger ones, since the former are more likely to use a strategy that requires spatial ability. Furthermore, individual differences in strategy used at any one age level may depend upon individual differences in spatial ability. Those children who are low in spatial aptitude may stick to a whole-word approach much longer than the average child, indeed a few may still use such a strategy in adulthood as Beilin and Horn (1962) have shown. Frederikson (1967) has presented data supporting this idea that aptitudes affect strategy choice.

On the basis of the above analysis, it was expected that spatial ability would correlate with anagram performance for those cases where letter rearrangement is the predominant strategy. Therefore, anagram performance should be more predictable from spatial ability scores for older children than for younger ones. Furthermore, spatial ability should correlate more highly with older children's performance on nonsense anagrams (where they are more likely to rearrange letters) than it does with their performance on word anagrams (where they tend to use a whole-word strategy). This differential between word and nonsense anagrams can be explained by Gestalt principles which predict that it is easier to break apart (perceptually) nonsense anagrams than it is to do so for word anagrams.

METHOD

Subjects

The subjects were public school children in Palo Alto, California. There were 24 boys and 24 girls tested in each of three grade levels, second (mean age of 7 years, 11 months), fifth (mean age of 11 years, 2 months), and eighth (mean age of 13 years, 11 months). The only selection criteria used were that subjects have no perceptual abnormality, no outstanding reading disability, and not be bilingual.

Materials

Aptitude tests. Five aptitude tests were administered: two measures of decentration, two measures of linear spatial visualization, and one measure of general spatial ability.

(1) *Decentration* is the ability to free oneself from the given or dominant perceptual configuration and to analyze that configuration into its component parts, thus making possible a new perceptual organization of the given stimuli. The content of one of the decentration tests was figural and the content of the other was symbolic.

(a) Three-letter Words: This is a slight modification of a test developed by Bechtoldt (1969), the only change being in the length of the words (in order that the difficulty level be appropriate for very young children). The test consists of lines of equally-spaced letters within which can be found three-letter words, randomly-spaced. The subject's job is to circle all of the three-letter words he can find.

(b) Hidden Patterns: This is a test developed by Thurstone (1944) which consists of a given model figure and a number of more elaborate choice figures. The subject must indicate in which of the choice figures the model is embedded.

(2) *Linear spatial visualization* is the ability to manipulate figures and symbols which differ in their linear order from the given arrangement. One figural content and one symbolic content test were used to measure this ability.

(a) Jumbled Letters: This test consists of a string of three to five letters with arrows indicating possible new positions for these letters and thus a new left-to-right order for the given string of letters. In addition, there are a number of possible rearrangements presented, and the subject's task is to indicate which of these possibilities represent the new order that would result from rearranging the letters as indicated by the arrows.

(b) Jumbled Figures: This test differs from Jumbled Letters only in content, the stimuli being familiar shapes (circles, triangles, etc.) rather than symbols.

(3) *General spatial visualization* is "the ability to apprehend visually the spatial arrangements of things in one's psychological field" (Guilford, 1967, p. 93). This was measured by Card Rotations, a widely-used test developed by Thurstone (1938).

Reading achievement. Reading level was measured by standardized tests administered by the schools. For the second graders this was the Stanford Achievement Test (SAT), Form 4F—Primary IW. For the fifth graders the measure was the Sequential Test of Educational Progress (STEP), Level/Form 4A. For eighth graders it was also the STEP, Level/Form 28.

Anagrams. The anagrams were constructed to vary systematically on the following parameters.

(1) *Solution-word frequency*: High frequency words were all (a) AA words in the Thorndike-Lorge (1944) adult count (found at least 100 times in 1 million words) and (b) greater than 500 in the juvenile count (found at least 500 times in 4.5 million words in 120 juvenile books). Low frequency words were all (a) less than 100 in the adult count and (b) less than 500 in the juvenile count. One addititional criterion was that all subjects know all the words in written form. This was assured by pre-testing the words on second graders.

(2) *Solution-word letter transition probability* (LTP): The Mayzner and Tresselt Tables of Bigram Frequencies (1965) were used for computing letter transition probabilities. They indicate the number of times that a given bigram was found in a given position in words of a given length in their count of 20,000 English words. The LTP of a word is computed by summing all of the bigram frequencies for that word. For high LTP solution-words the mean LTP was 296; for low LTP solution-words the mean was 174.

(3) *Anagram letter transition probability*: The LTP of each anagram *stimulus* was calculated and the anagrams were chosen so as to equate

anagram LTP's as nearly as possible, thus avoiding differences in solution-times due to the effects of the LTP of the anagram stimulus. Thus, throughout this study LTP of *solution-word* is systematically varied while LTP of *anagram* is equated across various types of anagrams.

(4) *Anagram type*: The stimulus presented to the subject was either a word (word anagram) and his task was to make another word using all of the letters presented but no additional ones, or the stimulus was a nonsense arrangement of letters (nonsense anagram) and the subject's task was to make a word using all of the given letters and only those letters.

(5) *Word length*: The stimulus (and thus the solution-word) was either three letters or five letters long.

Design

There were four different lists of 32 anagrams per list. Each list contained two instances of every possible combination of the above four parameters (they were equated on the fifth parameter, anagram LTP). The order of the various types of anagrams within a list was systematically counterbalanced so as to control for any order effects. Each subject received one of the four lists (32 anagrams). Thus we have a six-way design with the following factors: age (second, fifth, and eighth graders), sex (boys and girls), anagram type (word and nonsense), solution-word frequency (high and low), solution-word LTP (high and low), and anagram length (three letters and five letters).

Procedure

Every subject was tested individually by one of four experimenters. The five aptitude tests were administered first followed by the 32 anagrams. Each anagram was in block letters on 3 × 5 cards. The subject was allowed one minute in which to produce the correct solution. If he succeeded in less time, the number of seconds to solution was recorded and he proceeded to the next one. If he did not find the right answer within one minute, he was given a score of 60 sec. for that anagram, told the correct answer, and then directed to go on to the next anagram.

RESULTS AND DISCUSSION

Anagram Measure

There were two different measures of performance on anagrams, (1) solution-time and (2) whether or not the solution was arrived at within the time-limit. Following the advice of Winer (1962) the time scores were transformed to logs and the number correct scores were transformed according to the formula, $x_{transformed} = \sqrt{x_{observed}} + \sqrt{x_{observed} + 1}$. As in previous studies, the correlation between these two measures was very high: .89 for second graders, .83 for fifth graders, and .81 for eighth graders. Since the pattern of results is very similar for the two different measures, only the analysis using number correct scores will be presented here.

Table I presents the means and standard deviations of both the raw and transformed scores by grade.

Preliminary tests revealed no experimenter nor anagram order effects.

Aptitude Measures

The means and standard deviations of the aptitude measures are presented by grade in Table II and their intercorrelations appear in Table III.

The two tests used to measure decentration, Hidden Patterns and Three-letter Words, correlated significantly with one another for second and eighth graders but not for fifth graders. In addition, it should be noted that decentration was soundest as a construct for eighth graders. The two measures of decentration correlated .43 with one another and also both correlated significantly with eighth graders' reading achievement. Thus there seems to be some justification for considering them measures of the same factor. On the other hand, word recognition is required in Three-letter Words, a process not at all involved in Hidden Patterns.

Jumbled Figures and Jumbled Letters were highly correlated with each other at all grade levels. However, neither correlated significantly with Card Rotations except for grade 2 where Jumbled Figures was significantly related to Card Rotations. This difference between the general spatial ability measure and the linear spatial ability measures seems to indicate that the two different kinds of

TABLE I. Means and Standard Deviations of Raw and Transformed Anagram Scores (Number Correct) by Grade

	Grade		
	2	5	8
Raw Score			
Mean	18.63	23.42	26.60
s.d.	5.27	3.68	2.96
Transformed Score			
Mean	8.64	9.75	10.40
s.d.	1.03	.77	.69

Note. All figures are based on 48 cases.

TABLE II. Means and Standard Deviations of Aptitude Tests by Grade

	Grade					
	2		5		8	
Aptitude Test	Mean	s.d.	Mean	s.d.	Mean	s.d.
Hidden Patterns (maximum=100)	8.56	3.46	15.65	6.50	29.04	8.81
Three-letter Words (maximum=40)	6.25	3.55	12.52	3.85	18.29	5.98
Jumbled Figures (maximum=30)	25.63	3.74	27.35	2.51	28.73	1.76
Jumbled Letters (maximum=30)	26.06	3.99	27.98	2.36	29.08	1.88
Card Rotations (maximum=112)	20.71	5.52	26.63	5.33	36.17	8.87

Note. All figures are based on 48 cases.

measures are quite independent. Although Card Rotations is considered a measure of *general* spatial ability, it actually only requires the ability to visualize *rotations*; Jumbled Figures and Jumbled Letters require the ability to visualize linear (left to right) spatial rearrangements.

Relation of Aptitude Measure to Anagram Performance

Decentration. Hidden Patterns, the measure of decentration with figural content, did not correlate significantly with the anagram performance of any of the three grade levels. Three-letter Words on the other hand, the symbolic measure of decentration, correlated significantly with total anagram score for all three grade levels (see Table III).

The above analysis of the anagram task and of strategies used in it

TABLE III. Correlations Between Aptitude Tests and Anagram Performance by Grade

	Hidden Patterns	*Three-letter Words*	*Jumbled Figures*	*Jumbled Letters*	*Card Rotations*	*Reading Achievement*
Three-letter Words	.28* .10 .43**					
Jumbled Figures	.20 .32* .13	.25 .38** −.09				
Jumbled letters	.30* −.02 .20	.23 .25 −.16	.70** .44** .88**			
Card Rotations	.26 .27 .18	.27 .04 .05	.28* .09 .11	.18 −.18 .17		
Reading Achievement	.25 .14 .33*	.20 .16 .38**	.05 .24 .31*	.22 .19 .19	−.05 .00 .14	
Total Anagram Score	.15 −.06 .08	.50** .34* .39**	.18 .29* .05	.06 .33* −.06	.06 .23 .00	.33* .37** .33*
Word Anagram Score	.00 −.05 −.08	.44** .29* .46**	.13 .08 .02	−.02 .20 −.06	−.06 .33* −.06	.20 .23 .13
Nonsense Anagram Score	.27 −.05 .24	.49** .37** .09	.21 .38** .06	.13 .38** −.02	.18 .23 .07	.43** .42** .40**

*$p < .05$

**$p < .01$

Note: The first figure in each cell is the correlation for 2nd graders, the second for 5th graders, and the third for 8th graders. All correlations are based on 48 cases.

predicted this significant correlation between the ability to decenter and anagram performance: a letter rearrangement strategy is more efficient in most cases than a whole-word strategy, given a minimal knowledge of LTP's in one's language and given an anagram whose solution-word LTP is at least average. Thus, those subjects, at any age level, who are best able to decenter, are also those most likely to use a letter rearrangement strategy successfully simply because those who cannot decenter have no choice—they are unable to rearrange letters. Thus, those subjects most able to decenter also solve the most anagrams.

The discrepancy between Hidden Patterns and Three-letter Words in their relations to anagram performance is undoubtedly due to their differential content. Hidden Patterns is a general figural measure of decentration and the content of both parts and wholes has little meaning. Three-letter Words is a verbal-symbolic measure and its parts (three-letter words) are meaningful. Thus, the content of the Three-letter Words task is more similar to that of anagrams than is the content of Hidden Patterns. In addition, Three-letter Words requires word recognition, as does anagram solving when a letter rearrangement strategy is employed.

Closer analysis reveals the following: for eighth graders, Three-letter Words correlated significantly only with word anagram performance. The lack of a relationship between Three-letter Words and nonsense anagrams seems to be due to the fact that almost all eighth graders are able to decenter sufficiently to employ a letter rearrangement strategy on nonsense anagrams. Decentration does not differentiate between fast and slow solvers because both types of subjects can decenter adequately for the task, and thus decentering ability does not account for individual differences in performance. Following this line of reasoning, why is there a correlation between decentration and eighth graders' performance on word anagrams? As argued above, it is more difficult to break down a word into its component parts than it is to break down a nonsense arrangement. This Gestalt effect explains why word anagrams are more difficult for adults than nonsense ones. Therefore, it seems likely that perceptual decentration has developed in eighth graders sufficiently so that almost all of them can break a nonsense anagram into its component parts, but not sufficiently so that most of them can break a word anagram into its component parts. Thus, decentration still differentiates between fast and slow solvers on word but not on nonsense anagrams.

Spatial ability. The general measure of spatial visualization, Card Rotations, was not significantly related to total anagram performance at any of the three age levels (see Table III). Jumbled Figures and Jumbled Letters, the two measures of *linear* spatial visualization, were unrelated to the anagram performance of second graders and of eighth graders, but they were both significantly correlated with the fifth graders' total anagram score. This is consistent with the analysis presented above that Card Rotations measures the ability to visualize *rotations* while Jumbled Letters and Jumbled Figures measure the ability to visualize *linear* (left-right) rearrangements.

The lack of correlation for second graders between anagram performance and linear spatial visualization is consistent with the hypothesis that they are using a whole-word strategy. For fifth graders, closer analysis reveals a significant relation between linear spatial ability and nonsense anagram performance but no such relation for word anagrams (see Table III). This is consistent with both the theory and findings on decentration reported above. Older children seem to be able to break down perceptually a *nonsense* anagram into its individual letters or sub-groups of letters, and thus they tend to use a letter rearrangement strategy for which spatial ability is important. On the other hand, they have more difficulty in breaking down a *word* anagram for which they therefore use a whole-word strategy and diminish the importance of spatial ability.

The eighth graders show no relation between linear spatial ability and word anagram performance for the same reason as fifth graders. However, the predicted correlation between spatial ability and performance on nonsense anagrams was not confirmed. This appears to be due to a ceiling effect (see Table II) resulting in the standard deviations of scores on Jumbled Figures and Jumbled Letters decreasing as age increases. Thus these tests differentiate very little between older subjects high in linear spatial ability and older subjects low in that ability since almost all of the eighth graders have sufficient linear spatial ability to visualize rearrangements of strings of letters up to five units long. A linear spatial visualization test requiring the rearrangement of more than five letters or figures would certainly differentiate better among subjects. *However*, such a differentiation would be meaningless when it is at a level far above that required by the task.

A similar pattern of results is obtained by regressing anagram performance on decentration and examining the partial correlations of

TABLE IV. Partial Correlations of Jumbled Letters (Linear Spatial Visualization) with Anagram Scores after Regressing on Three-letter Words or Hidden Patterns (Decentration), by Grade

	Grade					
	2		5		8	
Anagram Type	*Three-letter Words*	*Hidden Patterns*	*Three-letter Words*	*Hidden Patterns*	*Three-letter Words*	*Hidden Patterns*
Word	.26	.08	−.11	−.17	−.08	−.15
Nonsense	.07	.00	−.34*	−.47**	−.03	.05
All	.18	.04	−.28*	−.35*	−.07	−.04

*$p < .05$
**$p < .01$

spatial ability with anagram performance as presented in Table IV. As expected, after regressing on ability to decenter there is no relation between linear spatial ability and anagram performance for second graders. For fifth graders there is a significant partial correlation for *nonsense* anagrams but not for *word* anagrams. For eighth graders there is no relation between linear spatial ability and either word or nonsense anagram performance when decentration is partialled out. These results are all strictly parallel to those presented immediately above and the same interpretation applies.

Reading Achievement

Previous studies (Elkind, et al., 1965; Stevenson and Odom, 1965; Stevenson, et al., 1968) have found positive correlations between reading achievement and anagram performance. The present study helps to specify the nature of this relationship: reading achievement correlated significantly with *nonsense* but not with *word* anagram performance (see Table III). A possible interpretation is that a letter rearrangement strategy (more likely for nonsense anagrams) requires the recognition of a string of letters as a word (i.e., reading) while a whole-word strategy (more likely for word anagrams) requires the subject to call up words from his word store and to see if their letters match those in front of him. The latter does not necessitate word recognition.

Summary

These results suggest that: (1) Piaget's theory of perceptual development as a process of increasing ability to decenter is a valid one, (2) the level of perceptual development plays an important role in the reading process, and (3) both perceptual development and individual aptitude differences are important determinants of children's problem solving strategies.

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