The Search for Structural Principles in Children's Manipulative Play: A Parallel with Linguistic Development

Barbara Dillon Goodson and Patricia Marks Greenfield

Stanford University

Goodson, Barbara Dillon, and Greenfield, Patricia Marks. *The Search for Structural Principles in Children's Manipulative Play: A Parallel with Linguistic Development.* Child Development, 1975, **46**, 734–746. Our study investigated the role of 3 structural principles —hierarchical complexity, interruption, and role change—in the development of children's construction play. The 3 principles are formally parallel to dimensions of language structure. Children from 2 to 6 were required to use varying combinations of structural features in order to build a series of modeled constructions. Predictions about the order of difficulty of our constructions, formulated on the basis of their constituent structural features, were confirmed by the results. Hierarchical complexity and role change, features of "deep structure," added significantly to the difficulty of a construction strategy. Interruption, a "surface-structure" feature, had, in contrast, a minimal effect. The results lend further support to the notion of a cognitive organization common to language and other modes of behavior.

The present study was designed to investigate whether there are structural principles common to linguistic behavior and manipulative play. The study examines the acquisition of manipulative strategies and compares them with previously studied language development involving the same structural principles.

This study has both theoretical and empirical roots. On the theoretical side is the notion that linguistic behavior is one of many possible manifestations of cognitive organization. Bever (1970), Piaget (1951), and Slobin (1973) relate linguistic structure to an underlying internal organization or cognitive base which may be manifested in and govern other behaviors as well. Piaget and Slobin connect developmental forms in language to stages of cognitive development, and Bruner (1968) raises the possibility of grammar-like programs of action starting early in infancy. The notion of cognitive organization common to language and other domains also follows from the theoretical position of the generative semanticists (e.g., Lakoff 1971; McCawley 1968), who postulate a semantic basis for grammar. In contrast, transformational grammar (as represented by Chomsky, e.g., 1965) excludes meaning from grammar and has led to the psycholinguistic notion of cognitive capacities *unique* to language (e.g., McNeill 1970).

On the empirical side, Huttenlocher and her colleagues (Huttenlocher, Eisenberg, & Strauss 1968; Huttenlocher & Strauss 1968) showed that, when a child manually arranges one object relative to another, there is a psychological correspondence between the moving object and the logical and grammatical subjects of a sentence. Greenfield, Nelson, and Saltzman (1972) extended this conception of a language-action parallel to the development of a unified sequence of related actions in naturally occurring manipulative play. They found that the developmental progression of combinatorial strategies was exactly parallel to the development of analogous language

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structures. A second study, by Greenfield and Westerman (1973), showed that this formal parallel between language and action is not merely an analogy but involves psychological relations between the two modes.

Harris (1972) approached this same question of parallels between action and language through a study of development in both modes. One hypothesis was that common structural features in verbal forms and nonverbal object manipulation tasks would produce the same order of acquisition in each mode. The hypothesis was confirmed for a limited subset of the tasks and language structures. One problem was that the materials for the nonverbal tasks were so heterogeneous that they differed along many dimensions besides the strictly structural ones defined by Harris. Hence, the resultant order of acquisition would not necessarily reflect structural factors alone. Thus, it is hard to interpret Harris's results as either confirming or disconfirming the hypothesis of parallel developmental sequences in language and object manipulation. The present study, as well as the earlier one by Greenfield et al. (1972), searches for a progression of structurally distinct manipulative patterns using a single set of materials. In this way, all factors other than the structural ones being studied are under experimental control.

The present study investigates the role of three structural dimensions or principles in more complex combinatorial activity than has been previously studied. The three dimensions are hierarchical complexity, interruption, and role change. Each dimension also relates to a dimension of grammatical/semantic structure and to the use and development of language. The level of analogy suggested is that of structural principles operating in both language and action, but not specific to either, which determine relative cognitive complexity within each domain. An attempt was made to demonstrate that interelement relationships previously described for language also apply to construction play, without assuming equivalence of individual elements across the two modes. The pieces used in a play construction are not considered to be analogous to specific words in sentences, nor are final constructions assumed to be equivalent to specific sentences or linguistic structures.

Hierarchical Complexity

Language is hierarohically organized by its very nature. Just as for other levels of linguistic organization, the hierarchical complexity of syntactic relations increases with development. For instance, children form a series of simple sentences before they embed one proposition in another in a hierarchically more complex sentence structure (e.g., Brown 1973; Limber 1973).

Greenfield et al. (1972) found a similar developmental progression in the manipulation of seriated cups. The subassembly strategy, the last to appear developmentally, involves the most complex hierarchical organization. In this strategy, two cups were combined and then moved as a unit into or onto a third cup, creating a subordinate/superordinate relationship between multicup units. The two earlier strategies involved one less level of hierarchy in that cups were combined only one at a time to form the final structure.

In an unpublished manuscript, Wood and Ross investigated the development of construction routines for assembling a hierarchically structured puzzle toy consisting of five pyramidal levels. Each of the first four was constructed by joining two subunits consisting in turn of two individual pieces. The hierarchical structure required by this puzzle developed gradually with age. Forman, Laughlin, and Sweeney (1971), using a jigsaw puzzle task, also found evidence of increasingly complex hierarchical organization. Studies of perception (Anisfeld 1968; Elkind, Koegler, & Go 1964), class inclusion (Inhelder & Piaget 1964), and conceptualization of recursive thought (Miller, Kessel, & Flavell 1970) offer further evidence that hierarchical complexity predicts difficulty and developmental sequence in cognitive tasks.

These empirical studies illustrate the general principle formulated by Werner (1940) that developmental change is characterized by increasing differentiation and hierarchical integration, that is, increasingly complex hierarchical organization. Miller, Galanter, and Pribram (1960) and Newell, Shaw, and Simon (1958) took hierarchical structure as central to their analyses of the organization of behavior. Neither group dealt with the ontogenetic development of these hierarchies. Miller and his colleagues were, however, concerned with the microdevelopment of hierarchical structure that adults acquire in learning new motor skills.

Bruner (1968; see also Bruner & Bruner 1968) recently put forth evidence for an ontogenetic theory of skill involving progressive hierarchical complexity. Bruner bases his ideas in part on Lashley (1956), who rejected chaining in favor of syntax as a basis for the organization of serial skilled action. Our study, in contrast, investigates chaining and syntax (more complex hierarchical organization) as two points in a developmental progression.

The background of our first hypothesis indicates that action strategies requiring more complex hierarchical combination should be more difficult and therefore would be acquired later in development than strategies involving less complex hierarchical combination.

Interruption

The second structural dimension concerns interruption. Bever (1970) hypothesized that the more interruption of a grammatical sequence by an intervening subsequence, the more complex the sentence. In his view, this stemmed from the application of a universal perceptual restriction to language. Slobin (1971) expressed a similar notion. Psycholinguistic data relevant to this hypothesis come primarily from experimental comparisons of center-embedded (nested) relative-clause sentences and left- or right-branching ones. A center-embedded sentence involves interruption of the main clause (e.g., "The boy who was sick stayed home"), whereas a left- or right-branching one does not (e.g., "The boy stayed home, where he belonged"). Three imitation studies (Baird 1969; Slobin & Welsh 1973; Smith 1970) seem to provide evidence that center-embedded sentences are more difficult than left- or right-branching ones. Two studies of spontaneous production (Limber 1973; Menyuk 1969) found that relative clauses which modified objects (left or right branching) occurred earlier and more frequently than those modifying subjects (center embedded). Some studies have demonstrated an adverse effect of interrupted constituents on comprehension (Gaer 1969; Lippman 1970), while other, seemingly better controlled studies have not (Brown 1971; Sheldon 1972, 1973). Sheldon's findings are discussed in detail in the next section.

If, as Bever (1970) and Slobin (1971) suggest, the difficulty of center-embedded sentences is a special case of cognitive interruption, then it should be possible to find an analogous effect of interruption on other domains. In language, interrupted structures require the processor to remember the first part of the main clause while processing the second, subordinate clause so that the first clause can then be completed. In construction play, one unit is begun and left uncompleted while a second, subordinate unit is built. Thus, the first unit must be kept in mind in order to complete it.

This notion of a memory load imposed by interruption led to the prediction that manipulative strategies in which interruption of a unit was required would be more difficult and would be acquired later developmentally than would action strategies in which no interruption occurred.

The principle of interruption operates at the surface-structure level in language. Interrupted versus noninterrupted sentences differ in their temporal or spatial relationships between units but not necessarily in their underlying semantic/grammatical relationships. It seemed potentially fruitful to make a parallel distinction between surface structure and deep structure in construction play. Analogous to language, interruption in action was considered to be a surface-structure dimension. Surface structure is defined as the order of combination of the construction elements. Deep structure is the set of relationships among the elements, that is, how elements function in the action with respect to each other.

Role Change

The third structural factor investigated was role change. This dimension relates to whether a single element plays similar or different roles in relation to different parts of a complex structure.

Sheldon (1973) hypothesized that role change (which she calls nonparallel function) operates in language and accounts for developmentally related difficulties with certain relative-clause forms. Her study compared the effect on sentence comprehension of role change, interruption, and inverted word order. Subjects from 3-8 to 4-6 demonstrated comprehension by correctly acting out the four sentence forms represented below, using small animal figures:

1. The dog bit the *cat* that chased the rabbit.

2. The *dog* that chased the rabbit bit the cat.

3. The *dog* that the rabbit chased bit the cat.

4. The dog bit the *cat* that the rabbit chased.

Relative-clause sentences where the coreferential nominal (italicized) has the same grammatical function in both clauses (sentences 2 and 4) involve no role change. Where the coreferential nominal (italicized) acts as the subject of one clause and the object of the other, the sentence involves role change (sentences 1 and 3).

Sheldon's parallel-function (role-change) hypothesis predicted that sentences 2 and 4 would be easier to process than 1 and 3. Because the main clause is interrupted by the subordinate clause in sentences 2 and 3, the interruption hypothesis predicts that 1 and 4 will be easier to process than 2 and 3.

While the sentences involving role change were associated with significantly more errors, according to an analysis of variance, those with interruption were not. Nevertheless, within the group of sentences involving role changes the center-embedded (interrupted) sentences were harder for all age groups and a replication group. Within the group of sentences not involving role change, the interrupted sentences were more difficult than uninterrupted ones for the youngest two groups and the replication group. Thus, seven out of eight comparisons showed differences in favor of the noninterrupted sentences. While there is no question that role change made the largest contribution to difficulty, interruption, our second structural dimension, may have contributed to processing difficulty as well.

Sheldon also tested the same group of children on conjoined forms of the relativized sentences in order to assess whether semantic or syntactic relationships were crucial to the effect of role change. For instance, the conjoined form of sentence 1 was "The dog bit the cat and the cat chased the rabbit." She found that children performed at a similarly high level on all four conjoined forms. The explanation for these results may be that the negative effect of role change on comprehension is lessened under conditions of decreased structural complexity; clearly, the coordinate sentences lack the hierarchical complexity of their relativized counterparts. Processing time might have revealed this smaller effect more easily than number of errors, the only variable measured.

Applying the concept of role change to action requires an analysis of the combinatorial relationships among the elements in an action that is analogous to describing the semantic relationships underlying a linguistic structure. In both action and language, role change concerns relationships at the deep-structure level. Case-grammar analysis of language was the model for describing semantic relationships in action. In case grammar, the sentence is described in terms of a verb (representing an action or state) and the roles of the nouns (representing entities) in that action or state. In an action strategy, the elements can be described in terms of the roles in which they function in the action of construction. In any object manipulation, the child doing the constructing is the overall actor in every step of the action. However, the objects themselves can be assigned roles on the basis of their interrelationship in the construction process. When two elements are combined in an asymmetrical way, one moves or "acts" while the other is relatively stationary, serving as the locus or recipient of the action. Adapting Fillmore's (1968) case-grammar framework for the description of action, we could say that the more active piece functions as instrument, where instrument is defined as "the inanimate force or object causally involved in the action" (Fillmore 1968, p. 24). The stationary piece, in contrast, functions simultaneously as object and locus of the instrument's action. Continuing our adaptation of Fillmore's framework, we can define objects as "things which are affected by the action" and locus as "the location or spatial orientation of the . . . action" (1968, p. 25). Because the stationary piece both is acted on by the instrument and serves as the locus of its action, this role is termed "object/locus," combining the concepts behind two of Fillmore's cases, the objective and the locative. Our terminology for labeling action roles has been changed since our first study (Greenfield et al. 1972) for the sake of greater clarity and precision. More critical than actual labels, however, is the relation of active to passive when two pieces are combined; this idea has remained constant from the first study. Role change was defined for action on the basis of this active-passive or instrument-object relationship. If an individual piece changed from passive object/locus to active instrument in the course of a construction, then role change was considered to have occurred.

Greenfield et al. (1972) found, in the context of seriated cups, that a manipulative strategy—the subassembly described earlier—in which one piece changed from a passive to an active role during construction was the last to develop. Since the subassembly was the most complex in terms of hierarchical complexity as well as role change, these two variables were confounded in that study. The present study investigates these two structural factors separately.

The goal of this study was to demonstrate the effect of all three structural dimensions on the development of combinatorial activity with objects. Specific hypotheses are presented in the next section.

Method

Experimental materials and their rationale.—The materials used in this study were chosen for their applicability to the three structural dimensions noted above. They consisted of a Playskool construction set with five shapes: green wooden blocks, red wooden wheels, tan wooden boards, yellow plastic bolts, and green plastic nuts. The board pieces were 2½ cm wide and came in three lengths: 9, 15½, and 21½ cm. The blocks were 3½ cm on a side. The bolts were 3½ cm long and 1 cm wide. Two structures were designed from these materials. One was a bench of five pieces, and the second was a propeller of four pieces.

The bench can be constructed from the same five elements by two alternative strategies. Each strategy constitutes a description of the construction process. In both plans of action for constructing the bench shown in figure 1, the elements function in the same roles with respect to the other elements: the same pieces are relatively more or less active, and each element maintains one role throughout the action. A difference in the superficial order in which pieces are combined introduces interruption into the second strategy: the child begins one side or subunit of the bench and then leaves it to work on the other side. In the end, he or she must remember to return to the first side to complete it. This process is depicted in the right column of figure 1; step 2 shows the point of interruption. Subassembly with interruption contrasts with simple subassembly, shown in the left column of the figure. In that strategy, one side or subunit of the bench is completed (step 3) before the second

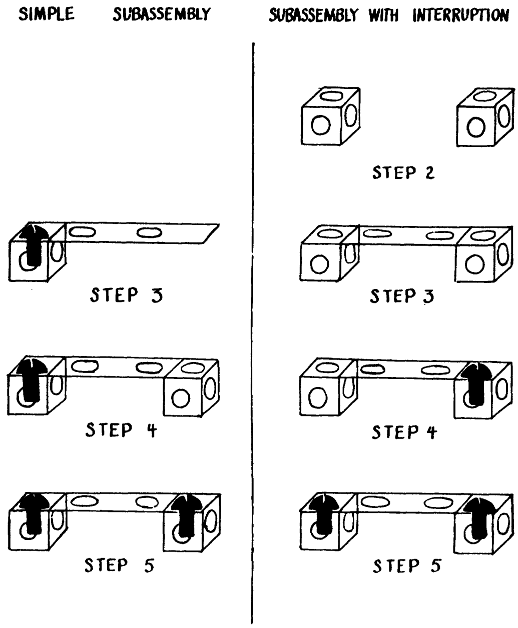

Fig. 1.—Action strategies for constructing bench

one is begun. The difference between the two strategies is analogous to two linguistic structures with the same underlying semantic/grammatical relationships but differing on the level of surface structure. Subassembly with interruption was hypothesized to be cognitively more complex than simple subassembly, because of the interruption factor.

An identical propeller could also be built using two different manipulative strategies. The two strategies involve different underlying semantic relationships among the elements. These relationships were inferred from direct observation of the construction process. In this respect, construction activity differs from language, for the underlying semantic relationships of a sentence are not observable in the act of uttering it.

The first construction strategy for the propeller is piling. Figure 2 shows a tree structure representing the underlying relationships of component parts for this method of construction. The piling strategy involves a series of pairings, with the same piece (nut or bolt) always functioning as the recipient of the action and defining the locus of the action in each of the asymmetrical pairings. Action, corresponding to the verb in Fillmore's (1968) scheme, occurs when the pieces on a single-level hierarchy are combined with each

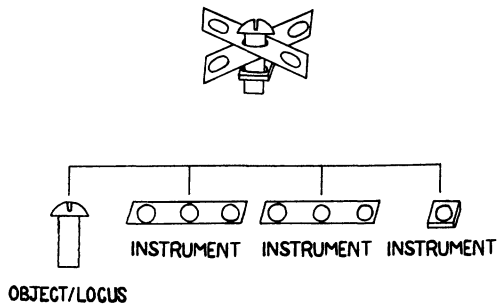

FIG. 2.—Hierarchical structure of piling, one strategy for constructing propeller. If child started with nut rather than bolt, nut would be the object/locus, bolt an instrument. In either case, piling strategy would involve a single object/locus and multiple instruments, its defining feature.

other. The single-level structure in figure 2 indicates that the acting elements can be used in any order. Had the strategy been defined with the requirement that the nut come last, the tree structure could have had a second level to indicate that the bolt and two sticks formed a subassembly in themselves. From the psychological point of view, however, the single locus of action seems to be a more important criterion of subassembly than order constraints. This finding was the basis for the definition of the pot strategy in the study by Greenfield et al. (1972). (Piling in this study is structurally equivalent to the pot strategy. Due to the nature of the construction material used here, the term "piling" was felt to be more descriptive of the action strategy.)

The alternative strategy for constructing the propeller was called "subassembly with role change." Figure 3 shows a tree structure indicating both the underlying semantic relationships and the order of combination (from the bottom of the tree upward). The two stick pieces are first combined in a subassembly, which then becomes the instrumental unit in the next combination with a nut or bolt. Whereas in piling (fig. 2) the operative units are individual pieces, here two previously combined pieces function as a single unit or subassembly. Role change also occurs, since one of the stick pieces changes roles from stationary object of action in the first step to active instrumental element in the second step. The whole strategy involves two loci of action (two stationary objects of action), one stick and either the nut or the bolt. However, action at neither locus is interrupted. This strategy thus involves both subassembly and role change, but not interruption. (As in the tree representation of the piling strategy, an order constraint for placement of the nut [fig. 3] would add another level to the hierarchy.) A comparison of figures 2 and 3 indicates the hypothesized difference in hierarchical complexity for the two propeller strategies. This difference represents the fact that a subassembly action strategy always involves two loci whereas the potting or piling strategy has only one locus of action. Under either of the alternate representations of the propeller strategies, piling would have a less complex hierarchical structure than the three variants of subassembly used to construct the propeller and bench. A comparison of the two alternative methods for constructing the propeller, piling (fig. 2) and subassembly with role change (fig. 3), indicates that these differ in underlying structural relationships and superficial order of placement.

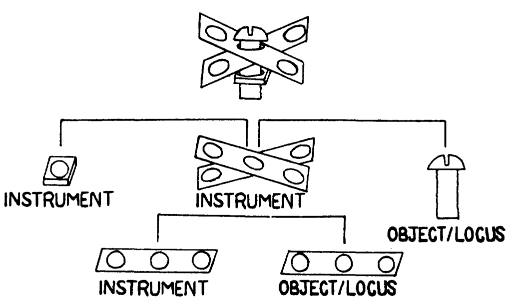

FIG. 3.—Hierarchical structure of subassembly with role change, alternative strategy for constructing propeller. If child used nut before bolt, nut would be an object/locus, bolt an instrument. The defining hierarchical structure of subassembly with role change would, in either case, remain the same.

The propeller was made of four pieces, compared with five in the bench, but the act of adding the propeller to the bench (fig. 4) was seen as requiring the use of a fifth piece, the bench. Thus, the two constructions were closely matched in terms of number of constituent elements.

Hypotheses.—One pole of each structural dimension was hypothesized to involve greater cognitive complexity: role change of a single piece in the same construction; interruption in the construction of one subassembly to construct another; more complex hierarchical relations among component pieces. The hypothesized order of increasing difficulty among the

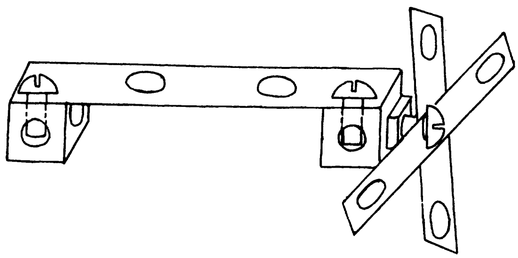

FIG. 4.—Completed combination ("airplane") structure.

four strategies, based on their combination of structural features (summarized in table 1), was piling, simple subassembly, subassembly with interruption, and subassembly with role change. Subassembly with role change and subassembly with interruption involve the same number of complicating features, as table 1 shows. The hypothesis that role change would introduce greater difficulty than interruption was based on Sheldon's (1972) findings with linguistic comprehension and our own pilot data. It was also hypothesized that there would be a scalar relationship among the four strategies such that the ability to use any strategy higher in the scale presumed the ability to use all strategies beneath it. For example, a child who was able to carry out the subassembly with interruption strategy should demonstrate piling and simple subassembly but not necessarily subassembly with role change. The scalar relationship among the strategies would be one line of evidence for an underlying developmental relationship. Our pilot data, based on 22 children, had supported these hypotheses.

Subjects.—Thirty-six white children from a private university nursery school and a public grade school drawing children from the same middle-class area were tested. There were three males and three females at each of the following ages: 24–30, 30–36, 36–38, 48–60, 60–72, and 72–84 months. The age range was based on our pilot work, which indicated that 100% of 8-year-old children were capable of using all four strategies without mistakes, and on the fact that children under 2 years would not be expected to do more than relate two pieces in an instrument-object relationship (from Greenfield et al. 1972).

Procedure.—The white female experimenter was not aware of the hypothesized relationships among the strategies. The children were tested individually at both the nursery school and the elementary school; mothers were present with the 2-year-olds. An introductory play period helped each child to feel at ease and to learn a screwing motion with the bolt. The toy materials were prearranged in a semicircular configuration on a table (fig. 5). The experimenter then presented a completed bench. The child was asked to build another bench just like the model. The experimenter noted which strategy the child spontaneously used in constructing his or her bench. When the child indicated completion, the experimenter disassembled her bench and said to the child, "I want you to watch while I build myself a bench. It will look just like the other bench and your bench when I am done, but I'm going to put it together in a different way. It will look the same, but I'll make it another way. Then I want you to build a bench in just the same way I did." The experimenter emphasized the process of building in her instructions and repeated them if the child seemed confused. Ensuring that the child was watching, the experimenter rebuilt the bench using the strategy alternative to that used spontaneously by the child. The experimenter pointed out to each child that there were enough pieces either to build an entirely new bench or to disassemble his or her first one.

TABLE 1

ORDERING OF ACTION STRATEGIES ON FACTORS OF COGNITIVE COMPLEXITY

Strategies	Hierarchical Complexity	Interruption	Role Change	Predicted Order (Least to Most Difficult)
Piling	...	...	...	1
Simple subassembly	X	...	...	2
Subassembly with interruption	X	X	...	3
Subassembly with role change	X	...	X	4

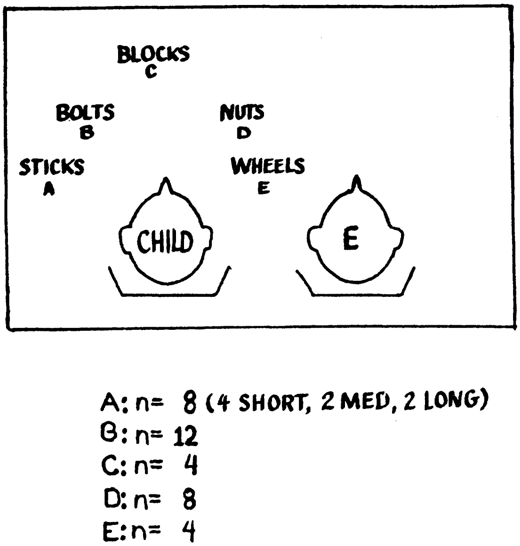

FIG. 5.—Array of construction materials

When the child finished the second bench, the experimenter took out a completed propeller (four pieces) and spun the blades for the child. The experimenter then screwed the propeller onto the bench (fig. 4) and said, "Now I have an airplane with a propeller. Could you make a propeller just like this one for your bench so that you'll have an airplane, too?" The same modeling procedure was then followed with the alternative propeller strategy.

The experimenter recorded each child's verbal comments and the order of combination of the pieces for a structure. On the basis of this record, the experimenter then classified each child's construction strategies as one of the four described. To be scored as using a particular strategy, a child did not have to end up with a perfect imitation of the model; he or she needed only to fulfill the basic definition of the strategy in the construction process. For example, a child would be given credit for simple subassembly if he or she reached step 4 depicted on the left side of fig. 1.

The "blind" experimenter and a second scorer agreed in their interpretations of the children's manipulative strategies on all but one of the first 36 children. This was 97% agreement. The single disputed subject was replaced by another child of comparable age.

Results

Sex and age.—The pattern of successes and failures for each child on the four strategies is shown in table 2. The data were first evaluated with an analysis of variance in order to test for the effects of age and sex on performance. The F values obtained for the sex $\times$ age interaction and for sex as a main effect were not significant. There was a significant main effect of age, $F(5,30) = 10.5$, $p < .001$. Consequently, males and females were combined within each age group, and sex was ignored in further analyses.

Competence and spontaneous performance.—Table 2 indicates which construction strategies each child manifested as well as those used spontaneously. These figures emphasize the importance of requiring the subjects to go beyond their spontaneous performance before interpreting their cognitive competence. Without an experimental design in which a second strategy was modeled, 18 out of 21 of the children who showed competence with both simple subassembly and subassembly with interruption would have been classified as having competence only with the former. In the same way, seven out of 14 of the children capable of both piling and subassembly with role change would have been underestimated in their competence. The experiment did not predict which of the two strategies for each construction would be used spontaneously. While the propeller elicited no consistent strategy preference, the bench did: the hypothetically less advanced strategy was preferred. For the bench, children able to construct it both ways used simple subassembly spontaneously a significantly greater number of times than subassembly with interruption, $p < .001$, according to a sign test.

Structural complexity and relative order of difficulty.—The actual order of difficulty (table 2) agreed perfectly with the predicted order of difficulty laid out in table 1; from easiest to hardest, this order was piling, simple subassembly, subassembly with interruption, and subassembly with role change. No age group showed results that contradicted the overall order of difficulty. Pairing had been identified as the strategy developmentally preceding piling in the earlier study of strategies for manipulating seriated cups. The one child in the present study who failed to pile was able

TABLE 2

Pattern of Success and Failures on Four Action Strategies

Average Age and Specific Age (Years-Months)	Action Strategies				Spontaneous Strategies		Scale Score
	P	S	I	R	Bench	Propeller	
2-3:							
2-0	+	−	−	−	...	...	1
2-1	+	−	−	−	...	...	1
2-2	−	−	−	−	...	...	0
2-2	+	−	−	−	...	...	1
2-5	+	−	−	−	...	...	1
2-6	+	−	−	−	...	...	1
2-10:							
2-7	+	−	−	−	...	...	1
2-8	+	+	−	−	...	...	2
2-10	+	−	+	−	...	...	2
2-11	+	+	+	−	S	...	3
2-11	+	+	+	−	S	...	3
3-0	+	+	+	−	S	...	3
3-8:							
3-6	+	+	−	−	...	...	2
3-6	+	+	+	+	I	R	4
3-8	+	−	+	−	...	...	2
3-9	+	+	+	+	S	R	4
3-10	+	+	+	−	I	...	3
3-10	+	+	+	+	S	P	4
4-7:							
4-4	+	+	−	−	...	...	2
4-4	+	+	+	+	S	R	4
4-5	+	+	−	−	...	...	2
4-8	+	+	+	+	S	P	4
4-10	+	+	+	−	S	...	3
4-11	+	+	+	−	S	...	3
5-5:							
5-1	+	+	−	−	...	...	2
5-1	+	−	+	+	...	P	3
5-5	+	+	+	+	S	P	4
5-6	+	+	+	−	S	...	3
5-6	+	+	+	+	I	P	4
5-10	+	+	+	−	S	...	3
6-3:							
6-0	+	+	+	+	S	R	4
6-1	+	+	+	+	S	R	4
6-2	+	+	+	+	S	P	4
6-3	+	+	+	+	S	P	4
6-3	+	+	+	+	S	R	4
6-11	+	+	+	+	S	R	4
$N = 36$	35	26	24	14	S = 18 I = 3	P = 7 R = 7	...

Note.—P = piling, S = simple subassembly, I = subassembly with interruption, and R = subassembly with role change.

to combine only two pieces in a pair.[1] Thus, this less advanced child confirmed the unity of the sequence earlier identified for materials having a very different character.

Tests were done to ascertain whether the overall difference in performance on the four strategies was a reliable one. A multivariate analysis was performed on the matrix of scores

[1] In free play after the testing session, this child's mother took apart the child's block/bolt pair and placed a stick on the block as if to begin a bench. When she asked her child to then put the bolt into the block through the stick, he first took the stick away and then added the bolt, which dramatized his inability to construct a three-piece combination.

formed by taking the differences between scores on adjacent strategies for each child (piling minus simple subassembly, simple subassembly minus subassembly with interruption, and subassembly with interruption minus subassembly with role change). Hotelling's T^2 indicated that the group of differences was significantly different from zero, $p < .01$. Simultaneous tests on the differences between the means indicated that the piling strategy was significantly easier than the simple subassembly strategy, $p < .05$, and that the simple subassembly strategy and the subassembly with interruption were significantly easier than the subassembly with role change, $p < .05$. There was not a significant difference between mean scores on the simple subassembly and the subassembly with interruption.

Qualitative differences in the children's performance on the four strategies confirmed the original hypotheses about which factors were responsible for the differences in the complexity of the strategies.

It was hypothesized that the feature which took the simple subassembly strategy beyond the cognitive requirements of piling was having to relate two units in a hierarchy. Five children working on the bench went no further than building up one side or unit by piling three pieces in one locus. They were capable of piling but could not use the resulting unit as a subunit in the construction of a large structure at another locus.

Subassembly with interruption was hypothesized to be more cognitively complex than simple subassembly because it required the child to keep one locus in mind while working at a second. The experimenter reported the most verbalizations with subassembly with interruption, which might be evidence of the increased processing difficulty posed by interruption. Children talked as they built ("First one screw, then the other screw"), almost as if they were helping themselves remember both loci during the construction. No child, by the way, eliminated the interrupted nature of this strategy by using both hands to place the two blocks simultaneously. The verbalizations of some children successful with the simple subassembly strategy were also revealing. They would complete the first three steps of the strategy (one side) and say, "There. That's done," or, "Now I'll make another one." These comments seemed to confirm that the children felt they were done with one subassembly when it was completed and were not required to operate on two simultaneously. This was also emphasized by the fact that children often picked up the entire half-completed bench (fig. 1, step 3) and turned it on its side or swung it around while constructing the second half. Once completed, the first subassembly functioned cognitively as a single piece.

The difficulty of subassembly with role change could have been due to the greater requirement of advanced motor skill in constructing the propeller. However, no children who attempted to build the subassembly failed due to lack of motor coordination. Some of the children used both hands to combine the sticks. In a completely symmetrical combination, the two pieces move simultaneously and the two are not easily differentiated as instrument and locus; yet the definition of role change depends on the attribution of the role of locus to one of the stick pieces. Our conceptualization of this situation is that, even when the child uses both hands, the two sticks have clearly different roles: one stick (the instrument) is always placed on top of the second stick (the locus).

The children seemed to have difficulty including the nut piece. Even children who demonstrated subassembly with role change by combining the two sticks and then the bolt could not add the nut. Their difficulty might have been due to the necessity of embedding the subunit within two other pieces, an accomplishment which transforms this strategy into subassembly with role change and interruption. The same principles which generated our other hypotheses led to the prediction, confirmed by the data, that this strategy would develop last. Sheer number of elements can be eliminated as an explanation of the difficulty of this strategy, for the easier strategy of subassembly with interruption actually involved as many elements in its minimal definition.

Scalability.—The four strategies were also examined as to their scalability: did the strategies form a developmental sequence? All but three out of the 36 subjects (91.7%) showed patterns of passes and failures that supported the hypothesized sequence. (That is, all but three showed no minuses in table 2 to the left of a plus score.) The technique of scalogram analysis was used to assess the scalability of the four strategies. Green's (1956)

Index of Consistency was chosen as the mathematical index. A perfectly scalable set of items, for which the index would equal 1.00, in comparison with the data in table 2 yields an index of .75. According to Green's criterion of scalability, $I > .50$, the four strategies of this study form a scale. The significance of the difference between the actual reproducibility of the scale and the chance reproducibility was highly significant, critical value = 5.45, $p < .001$. This indicated that the scalability of the four strategies was not merely due to sampling error.

To understand the developmental significance of the strategy scale, the correlation of scale score with chronological age was determined. With each child's age in months considered as a separate point, $r_p = .746$, $p < .001$. The correlation of scale type and age was quite high, considering that children would be expected to show individual variability in rate of development even when passing through an identical sequence of stages. The correlation is further evidence that the scalability of the children's responses reflected developmental relationships among the cognitive competencies underlying the strategies. Thus, analysis of the four strategies in terms of the factors of hierarchical complexity, interruption, and role change led to good predictions about the ontogenetic sequence of development.

Discussion

Three structural principles were hypothesized as governing cognitive behavior in two modalities: language and action. Previous psycholinguistic studies offered evidence of the operation of these structural principles both in contributing to the relative complexity (difficulty) of certain sentence structures and in influencing the developmental order of their acquisition. This experiment offers parallel evidence that these structural principles are involved in manipulative behavior. Knowing whether a structural feature is involved in a given action strategy allows for predictions both about the relative difficulty or complexity of that strategy and about its order of appearance in relation to strategies in which the feature is not involved.

The data from this study do not suggest that each strategy represents a separate point in cognitive development. Not all separations between pairs of strategies were significant. However, the data suggest that two developmental steps are involved: the acquisition of complex hierarchical structures and the acquisition of an ability to deal with role change. The ability to build constructions with three pieces in a single-object/multiple-instrument relationship (potting or piling) also seems to be a developmental step in the study of Greenfield et al. (1972); this was confirmed by the single subject who did not succeed in piling. It is interesting that interruption had the same marginal effect on object combination as it had in Sheldon's (1973) study of linguistic comprehension. While interruption alone affected competence very little, it was avoided where possible in construction activity, as in imitative and spontaneous language production (Baird 1969; Limber 1973; Menyuk 1969; Slobin & Welsh 1973; Smith 1970). Interruption, furthermore, was the only purely "surface-structure" feature of object combination studied in the present study, and it had the smallest impact on psychological complexity. Again, this behavior is parallel to psycholinguistic functioning where base-structure features generally influence linguistic processing more than do surface-structure features (e.g., Clark 1973). Merely to be able to operationalize a theoretical distinction between base structure and surface structure in the realm of action seems a promising step toward increasing our understanding of the organization of action and its interrelations with the linguistic system.

In contrast to the earlier study by Greenfield et al. (1972), we do not talk of behavioral strategies as "rules," because the criterion for a rule in the earlier study was *intra*individual strategic consistency over a number of trials. In the present study, however, because of the greater complexity of the action sequences, the children were given only one opportunity to manifest each action pattern. Hence, strategies were inferred from *inter*individual consistencies. "Strategy" was, in turn, preferred to Miller et al.'s (1960) term "plan," because, while implicit organization was inferred from behavior in the present experiment, degree of planning could not be. The term "strategy" seems to imply organization without necessarily implying anything about advance planning.

One final question concerns the meaningfulness of this language/action analogy. Unless the analogy is to be solely a formal one, it must be shown that these formal parallels between action and language have psychological consequences. As before (Greenfield & Westerman 1973), further psycholinguistic study should be used to assess the psychological meaning of the new language-action parallels demonstrated in the present study.

Our theoretical formulation has been in terms of common structural features in more than one domain rather than parallels between specific sentences and specific action patterns. A major reason for this is that, while any two domains may have similar principles of operation, the concrete manifestations possible may be quite different, due to design features of the two media. The more complex the behavior, the more this sort of divergence seems to occur. For instance, interruption in building the bench could take the form of center embedding, as in language (fig. 1), but it could equally well take the form of alternation (as if the order in fig. 1 were 1, 2, 3, 5, and 4) in which both subassemblies are interrupted before either is completed. This alternation form of interruption does not occur in language. Thus, it seems that an approach to the relationships between language and action in terms of structural principles rather than specific sentence-action parallels will prove ultimately applicable to much wider ranges of behavior.

Because these principles are so general, they guide development over and over in many specific acquisitions. For instance, hierarchy in language has many different meanings, and, at different times, many different developmental increases in hierarchical complexity occur. It is the same for action. Thus, subassembly with role change occurred at age 3 with seriated cups (Greenfield et al. 1972) and at age 6 in using nuts and bolts to build a propeller (the present study). What is common in both contexts is the structural progression of activity *within* that particular context: from piling to subassembly with role change. Note that the seriated cups do not even permit the expression of simple subassembly or subassembly with interruption. What we can conclude, however, is that insofar as the character of the objects permits the expression of the same strategies in two different contexts, the progression of stages will be the same, although they often occur at different times. This would be an example of horizontal *décalage* as Piaget defined it: a child operating at different levels of the same sequence of cognitive development with different materials. Because structural development refers to internal organization, it is not meaningful to make external comparisons across behavioral systems. This adds another reason to those developed by Greenfield et al. (1972) as to why correlations between developmental progress in two domains, for example, grammar and the manipulation of particular objects, are not presupposed by language-action parallels.

The positive findings of this study in terms of the original hypotheses add to a new perspective on language and cognition as well as manipulative play. Certainly the three structural principles examined here are not exhaustive and the developmental relations between the two domains remain to be elaborated. Clearly, though, continued investigation of commonalities between the organization of language and that of action will most certainly lead to an expanded understanding of both.

References

Anisfeld, M. Language and cognition in the young child. In R. S. Goodman (Ed.), *The psycholinguistic nature of the reading process.* Detroit: Wayne State University Press, 1968.

Baird, R. A developmental study of linguistic performance with sentences containing nested and embedded clauses. Unpublished doctoral dissertation, University of Washington, 1969.

Bever, T. G. The cognitive basis for linguistic structures. In J. R. Hayes (Ed.), *Cognition and the development of language.* New York: Wiley, 1970.

Brown, H. D. Children's comprehension of relativized English sentences. *Child Development,* 1971, **42**, 1923–1936.

Brown, R. *A first language.* Cambridge, Mass.: Harvard University Press, 1973.

Bruner, J. S. *Processes of cognitive growth: infancy.* Worcester, Mass.: Clark University, with Barre Publishers, 1968.

Bruner, J. S., & Bruner, B. M. On voluntary action and its hierarchical structure. *International Journal of Psychology,* 1968, **3**, 239–255.

Chomsky, N. *Aspects of a theory of syntax.* Cambridge, Mass.: M.I.T. Press, 1965.

Clark, H. H. Semantics and comprehension. In T. A. Sebeok (Ed.), *Current trends in linguistics.* Vol. **12**. *Linguistics and adjacent arts and sciences.* The Hague: Mouton, 1973.

Elkind, D.; Koegler, R.; & Go, E. Studies in perceptual development, II: Part-whole perception. *Child Development,* 1964, **35**, 81–90.

Fillmore, C. J. The case for case. In E. Bach &

R. T. Harms (Eds.), *Universals in linguistic theory*. New York: Holt, Rinehart & Winston, 1968.

Forman, G. E.; Laughlin, F.; & Sweeney, N. The development of jigsaw puzzle solving in preschool children: an information processing approach. Buffalo, N.Y.: Peabody Demonstration and Research Center in Early Childhood Education, 1971.

Gaer, E. P. Children's understanding and production of sentences. *Journal of Verbal Learning and Verbal Behavior,* 1969, **8**, 289–294.

Green, B. F. A method of scalogram analysis using summary statistics. *Psychometrika,* 1956, **21**, 79–89.

Greenfield, P. M.; Nelson, K.; & Saltzman, E. The and embedded clauses. Unpublished Ph.D. manipulating seriated cups: a parallel between action and grammar. *Cognitive Psychology,* 1972, **3**, 291–310.

Greenfield, P. M., & Westerman, M. Some psychological relations between action and language structure. Unpublished paper, 1973.

Harris, A. E. Cognitive skills in verbal and nonverbal behavior. Unpublished doctoral dissertation, University of Michigan, 1972.

Huttenlocher, J.; Eisenberg, K.; & Strauss, S. Comprehension relation between perceived actor and logical subject. *Journal of Verbal Learning and Verbal Behavior,* 1968, **7**, 527–530.

Huttenlocher, J., & Strauss, S. Comprehension and a statement's relation to the situation it describes. *Journal of Verbal Learning and Verbal Behavior,* 1968, **7**, 300–304.

Inhelder, B., & Piaget, J. *The early growth of logic in the child.* New York: Norton, 1964.

Lakoff, G. On generative semantics. In D. Steinberg & L. A. Jakobovitz (Eds.), *Semantics.* Cambridge: Cambridge University Press, 1971.

Lashley, K. S. The problem of serial order in behavior. In L. A. Jeffres (Ed.), *Cerebral mechanisms in behavior: the Hixon Symposium.* New York: Wiley, 1956.

Limber, J. The genesis of complex sentences. In T. E. Moore (Ed.), *Cognitive development and the acquisition of language.* New York: Academic Press, 1973.

Lippman, M. Z. The acquisition of noun modifiers: the relative clause and descriptive adjective. Unpublished doctoral dissertation, University of British Columbia, 1970.

McCawley, J. D. The role of semantics in a grammar. In E. Bach & R. T. Harms (Eds.), *Universals in linguistic theory.* New York: Holt, Rinehart & Winston, 1968.

McNeill, D. *The acquisition of language: the study of developmental psycholinguistics.* New York: Harper & Row, 1970.

Menyuk, P. *Sentences children use.* Cambridge, Mass.: M.I.T. Press, 1969.

Miller, G. A.; Galanter, E.; & Pribram, K. H. *Plans and the structure of behavior.* New York: Holt, 1960.

Miller, P. H.; Kessel, F. S.; & Flavell, J. H. Thinking about people thinking about people thinking about . . . : a study of social cognitive development. *Child Development,* 1970, **41**, 613–624.

Newell, A.; Shaw, J. C.; & Simon, H. A. Elements of a theory of human problem solving. *Psychological Review,* 1958, **65**, 151–166.

Piaget, J. *Play, dreams, and imitation.* New York: Norton, 1951.

Sheldon, A. The acquisition of relative clauses in English. Unpublished doctoral dissertation, University of Texas, Austin, 1972.

Sheldon, A. The role of parallel function in the acquisition of relative clauses in English. *University of Minnesota Working Papers in Linguistics and Philosophy,* 1973, no. 1.

Slobin, D. Developmental psycholinguistics. In W. O. Dingwall (Ed.), *A survey of psycholinguistic science.* College Park: University of Maryland, Linguistic Program, 1971.

Slobin, D. Cognitive prerequisites for the development of grammar. In C. Ferguson & D. I. Slobin (Eds.), *Studies of child language development.* New York: Holt, Rinehart & Winston, 1973.

Slobin, D. I., & Welsh, C. A. Elicited imitation as a research tool in developmental psycholinguistics. In C. Ferguson & D. I. Slobin (Eds.), *Studies of child language development.* New York: Holt, Rinehart & Winston, 1973.

Smith, C. An experimental approach to children's linguistic competence. In J. R. Hayes (Ed.), *Cognition and the development of language.* New York: Wiley, 1970.

Werner, H. *The comparative psychology of mental development.* New York: Harper & Row, 1940.