Developmental Psychology
1999, Vol. 35, No. 4, 1091–1101

0012-1649/99/$3.00

Problem Solving in Infancy: The Emergence of an Action Plan

Michael E. McCarty, Rachel K. Clifton, and Roberta R. Collard
University of Massachusetts at Amherst

Young children's strategies were evaluated as they grasped and used objects. Spoons containing food and toys mounted on handles were presented to 9-, 14-, and 19-month-old children with the handle alternately oriented to the left and right. The alternating orientations revealed strategies that the children used for grasping items. Younger children usually reached with their preferred hand, disregarding the item's orientation. In the case of the spoon, this strategy produced awkward grasps that had to be corrected later. Older children anticipated the problem, alternated the hand used, and achieved an efficient radial grip (i.e., handle grasped with base of thumb toward food or toy end) for both orientations. A model of the development of action-selection strategies is proposed to illustrate planning in children younger than 2 years.

The components of goal-oriented behaviors include selecting actions that are appropriate to the goal, correcting one's errors, persisting in one's efforts to achieve the goal, and stopping when the goal is achieved (Bruner, 1981; see also Miller, Galanter, & Pribram, 1960). The means or actions selected are of particular interest when multiple pathways are available in a problem-solving situation. If a person consistently selects actions that facilitate the realization of his or her goals, then one may be able to infer that the actions were planned in advance with respect to the goal.

In the infant and toddler literature, several goal-directed problem-solving tasks have been used. Infants may pull a cloth to get a string, then pull the string to retrieve a toy (e.g., Willatts, 1990). In this task infants have to choose which of two cloths to pull. Another task requires infants to select an appropriate tool from among many to rake in a desired toy (e.g., Brown, 1990). Both of these tasks focus on selection but do not include multiple strategies to distinguish and evaluate. Adolph (1997) presented infants with a problem-solving situation that engaged multiple strategies: navigation of surfaces that differed in degree of slope. Infants were tested going uphill and downhill for several weeks, including the transition from crawling to walking. Infants used a variety of exploratory tactics and strategies that depended on prior experience, as well as their proficiency in locomotion. A task that involved nesting a set of seriated cups revealed gradations in effectiveness of problem-solving strategies in children between the ages of 1 year 6 months and 3 years 6 months (DeLoache, Sugarman, & Brown, 1985). Such tasks that allow children to arrive at more or less elegant solutions that vary in their efficiency offer a valuable window into how the child conceptualizes the problem. In other words, the solution arrived at may reveal how the problem was represented. Furthermore, self-correction or errors can indicate the child's realization of a faulty strategy.

We introduced a problem-solving task for older infants and toddlers that was specifically designed to reveal developmental trends in strategy selection. The challenge of designing a problem-solving task that can be used over a wide age range with children under 2 years includes keeping motivation for the same goal high and motor requirements easy to meet at every age. In other words, the ideal task would allow children at every age to achieve the goal, and the different strategies used en route would allow inferences about how the problem was conceptualized and solved.

Our task involved the everyday experience of being presented with a spoon loaded with food. We assumed that most children will be tempted to consume a desirable food and that by 8–9 months of age all children will be capable of picking up the spoon and conveying it to their mouth. Not all children will be capable of self-feeding at this age (Connolly & Dalgleish, 1989), but they will have had several months' experience in picking up and putting objects into their mouths. We also assumed that by 9 months of age most children will be familiar with a spoon and being fed from a spoon. To turn this common situation into a problem-solving task, we altered the spoon's orientation over trials, so that the handle was alternately pointing to the child's left or right. This manipulation prevents repetitive action and forces the selection of different actions over trials if the child attempts to solve the orientation problem. Although the goal of food in the mouth can be achieved in many ways, some awkward and some smooth, we can designate one action as the most efficient: A radial grip on the handle of the spoon, featuring the thumb toward the bowl of the spoon, will bring food to the mouth quickly and without spilling. We assumed that the various behavioral patterns adopted by children will reveal both their conceptualization of the problem and their choice of a solution. Whereas some strategies will lead to physically awkward postures and ineffective solutions, others will avoid problems by advance planning. Consistent engagement in effective behaviors would indicate the adoption of an efficient strategy.

Michael E. McCarty and Rachel K. Clifton, Department of Psychology, University of Massachusetts at Amherst; Roberta R. Collard, School of Education (Emeritus), University of Massachusetts at Amherst.

This study was supported by the National Institute of Child Health and Human Development Grant HD27714 and by a Research Scientist Award (MH00332). We thank the parents and children who participated in this study, Kirsten Blount and Roselee Brown for their help in all phases of this project, and Marvin Daehler and Nancy Myers for comments on an earlier version of the manuscript.

Correspondence concerning this article should be addressed to Michael E. McCarty, Department of Psychology, Tobin Hall, University of Massachusetts, Amherst, Massachusetts 01003-7710.

The literature from human adults helped us predict what solutions the children may select. Rosenbaum and colleagues (e.g., Rosenbaum & Jorgensen, 1992; Rosenbaum et al., 1990; Rosenbaum, van Heugten, & Caldwell, 1996; Rosenbaum, Vaughan, Barnes, & Jorgensen, 1992; Rosenbaum, Vaughan, Jorgensen, Barnes, & Stewart, 1993) have done extensive work on the planning of action among adults in tasks that involve grasping and using a tool. To use a tool effectively, adults must plan and select actions in advance with respect to the goal. Two action-selection constraints are honored by adults: (a) a preference for keeping the joints in the middle of their range of motion during precise movements and (b) a preference for holding a tool with a radial grip. The first constraint facilitates precision because adjustments can be made more easily in the middle of the range of motion than at the extremes of the range of motion where action is less controllable or comfortable. The second constraint is thought to facilitate perception or attention toward the goal end of a tool because it remains visible through a wide range of wrist rotations in a radial grip but is obscured frequently by wrist rotations in an ulnar grip.

Rosenbaum et al. (1990, Experiment 1) varied the orientation of an object's action end in a manner similar to the one we have used here with infants. Adults were asked to pick up a horizontal dowel, painted half black and half gray, from a stand and place it on the table so that the black end (designated as the goal end) was on top. When the gray end (i.e., the "handle") was on the side of the preferred hand, the adult picked up the dowel with the thumb toward the black end, using the preferred hand and the overhand orientation. When the gray end was on the side of the nonpreferred hand, the adult adopted one of two solutions: (a) They used an underhand grip with the preferred hand to maintain the radial grip with thumb toward the goal end, or (b) they used the nondominant hand in the overhand orientation and made a radial grip with thumb toward the goal end.

The two solutions adopted by adults to solve the orientation problem require advance planning that coordinates the tool, choice of hand, and the grip, all in relation to the efficiency of the action to be performed. What might we predict about the developmental course of this action-selection process? At an early stage, the child would not recognize that the changing orientation of the spoon presented a problem at all. Presumably, the child would concentrate on the food itself, picking up the spoon without regard to orientation. We can predict the "typical grip" at this stage from two sources of descriptive data. First, emergence of a preferred hand may occur as early as 7 months (Ramsay, 1980). Second, a preference for the overhand orientation at grasp can be inferred based on the comfort of it in relation to the underhand orientation (Rosenbaum et al., 1990, Experiment 2) and based on the child's experiences of picking up objects off the floor or table where the underhand orientation is not an option. The typical pattern is thus predicted to be a reach with the dominant hand in the overhand orientation. If a child with a right-hand preference engaged in this pattern and ignored the spoon's orientation, this strategy would lead to radial grips when the handle was on the right, but awkward ulnar grips when the handle was on the left. At a later phase, the child will notice that the changing orientation of the spoon affects the outcome of transport to the mouth. We expect variability in behavior as the child attempts different strategies to cope with this realization. Ultimately, we predict that one of the two adult solutions will be adopted. To allow the choice of the underhand solution, we presented the spoon on a holder that raised it off the table's surface.

The effectiveness of an action-selection strategy can be evaluated at either the outcome or the process level. At the outcome level, the child can determine whether the strategy works. If food reaches the mouth, it is a successful outcome; otherwise it is not successful. At the process level, the child can determine the efficiency of successful strategies. Even if food reaches the mouth, some strategies create obstacles that must be overcome, whereas others avoid obstacles. A key component to learning in this situation involves going beyond the outcome level and evaluating performance at the process level. The motivation to act more efficiently may be the driving force that leads eventually to planful future-oriented behavior.

In addition to using a tool with a well-defined goal, we also presented children with items that had no clear goal or obviously correct way of being held (e.g., a toy animal attached to a handle). Comparing the children's behavior toward these items with their behavior with the spoon should reveal whether children reach in a particular manner toward items with a handle regardless of what the item is and how it may be used. We predicted that children would use more restricted strategies when reaching for an item with a well-defined goal.

Infants and toddlers from three age groups were tested to observe a range of strategies. These age groups vary in how much experience children have with using a spoon to feed themselves. Nine-month-olds usually have little self-feeding experience with a spoon; 14-month-olds typically have recently begun to use a spoon; and 19-month-olds generally have had several months of such experience (e.g., Connolly & Dalgleish, 1989; Gesell & Ilg, 1937).

In summary, the purpose of this study was to assess action selection in infants and toddlers in a problem-solving situation. Children reached for objects that varied in orientation from trial to trial, which enabled us to infer a child's strategies. The objects varied in the extent to which they were involved in a goal-directed problem to determine whether this would affect strategy selection. Finally, children from three age groups were included to encompass a range of strategies. We predicted that children's behavioral pattern changes over age would reveal the evolution of planning in advance to achieve a goal.

Method

Participants

Children's names were obtained from published birth announcements, and parents were contacted about the research through a letter and a phone call. Children who participated received a certificate of appreciation and a small gift (e.g., a T-shirt printed with the lab's logo). Thirty-six children were tested, 12 at each of three age groups: 9-month-olds (M = 9.3 months, SD = 14.3 days; 7 girls, 5 boys), 14-month-olds (M = 14.3 months, SD = 14.4 days; 7 girls, 5 boys), and 19-month-olds (M = 18.8 months, SD = 12.4 days; 6 girls, 6 boys). Six additional children were tested but were not included, 5 (one 9-month-old and four 19-month-olds) because they did not use a one-hand grasp on one of the items on a minimum number of four trials and 1 (a 14-month-old) because the videotape accidentally ended before the session was completed.

Procedure

Infants were brought into the laboratory by a parent and were given time to become familiar with the setting and the experimenter while the procedures were discussed with the parent and informed consent was obtained. Sessions were videotaped with a camera placed above and to the left of the infant, which allowed for an overhead view of both hands and the object presented. A timer display of the session was superimposed on the videotape with a time–date generator. The experimenter sat across a table from the infant, who sat either on a parent's lap or on a booster chair. All of the children received a standard order of warmup items, hand preference items, and experimental tasks.

The experimental tasks involved reaching for objects that have a "handle end" and a "goal end." These objects included an infant spoon (handle length 10 cm) whose bowl was loaded with food (usually apple sauce), a baby bottle (length 14 cm, width 5.5 cm) partly filled with juice, and toys with handles. In the case of the spoon and the bottle, the goal end is where food can be obtained; for toys on handles the goal end is the toy. The toys with handles included a bell, a rattle, a toy cow, and a toy pig (handle length was 8.5 cm for the bell and 15 cm for the other toys; goal end was 4 cm long and 7 cm wide for the bell and approximately 4 cm long and 3 cm wide for the other toys). Each item was presented horizontally and at midline for multiple trials. The goal end of the item was generally presented to the child's left and to the child's right on alternating trials. All of the items except the bell were presented on a wooden holder that supported the item at each end and kept the item 10 cm above the table (see Figure 1). The bell did not fit on the holder and was presented horizontally at midline with two hands by the experimenter approximately 10 cm above the table. Items were presented above the table to enable infants to use either an underhand or an overhand grasp. Before the first presentation of the spoon, parents were asked to spoon-feed their child one bite to encourage the child to reach for the spoon. To have enough data to examine individual grasping strategies, we required that each of the three item types be grasped four times. Only 9 of the 36 children were willing to grasp the bottle four times, so we excluded that item from all further analyses. The toys with handles were presented consecutively before the spoon was presented. The food items were presented late in the session so that the children would be more at ease in this novel situation.

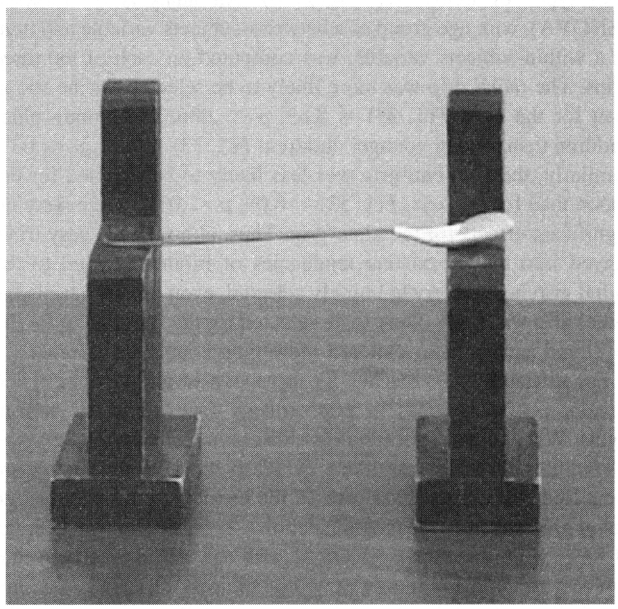

Figure 1. The infant spoon presented on the holder from the infant's perspective.

The hand preference items included a toy horse, a 1-in. cube, a cup, and a rattle presented with the handle toward the child. Each of these objects was presented at midline to permit an assessment of hand preference independent of the experimental tasks.

Scoring

Sessions were coded by viewing a videotape of the session at real speed and in slow motion or still mode if necessary. The coder noted which item was presented and its orientation, whether the item was grasped, which hand grasped the item, the location of the grasp (i.e., on the goal end or handle end), the hand's orientation (overhand or underhand) on the handle, and the placement (and order) of the goal end (or the handle end) of the item in the mouth. On the second pass through the videotapes, the coder scored spoon trials for time when the grasp occurred, when any part of the spoon entered the mouth, and when the bowl of the spoon entered the mouth. The difference between grasp time and bowl of spoon in mouth time was the *bowl-to-mouth duration.* The difference between grasp time and spoon in mouth time was the *spoon-to-mouth duration.* These durations were identical unless the handle of the spoon was first placed in the mouth. We do not have duration data for 5 of the children: two 19-month-olds never ate food from the spoon; and for 3 children (two 14-month-olds and one 19-month-old), the timer was not clear on the videotape, making it difficult to score.

Interrater reliability was assessed by having two coders score videotapes of 9 children, 3 from each age group, representing 25% of the data. A total of 187 trials were scored, and kappa ranged from .94 to 1.00 for scoring all of the items described above with nominal scales. A total of 64 spoon trials were scored for the duration coding. Reliabilities for determination of grasp time and bowl of spoon in mouth time were assessed with Pearson product–moment correlation coefficients, as these measures yielded continuously distributed scores (for grasp time, $r = .95$; for bowl of spoon in mouth time, $r = .90$). On percentage of agreement, the coders agreed (within 0.5 s) on 92% of trials on grasp time and on 89% of trials on bowl of spoon in mouth time.

Measures

The reach outcome of each trial was categorized as a one-hand grasp, a two-hand grasp, a miss, no reach, or a trial with a procedural error. A miss occurred when a child knocked the object off the holder onto the table and changed its orientation. A procedural error occurred when a child was holding another item when reaching for the current item (which may have affected the selection of the reaching hand). Reach outcome was determined at the moment the item was first grasped. Thus, if the item was grasped with one hand, the trial was coded as a one-hand grasp even if the other hand subsequently helped to stabilize or transport the item.

Three grips were identified. A *radial grip* occurred if the handle was grasped with the (base of the) thumb toward the goal end of the item. An *ulnar grip* occurred if the handle was grasped with the thumb away from the goal end of the item. A *goal-end grip* occurred when that end was directly grasped (i.e., the bowl of the spoon or the toy itself). (See Figure 2 for illustrations of the three grips.) If the item was grasped at the intersection of the handle and the goal end of the item, this was coded as a radial or ulnar grip and not as a goal-end grip.

The hand grasping the spoon was identified in relation to the spoon's orientation. The *handle-side hand* was the hand on the same side as the handle. For example, in the radial grip illustrated in Figure 2, the grasp was with the handle-side hand because the handle was to the right and the right hand was used. The *bowl-side hand* was the hand on the same side as the bowl. For example, in the ulnar and goal-end grips illustrated in Figure 2, the grasp was with the bowl-side hand because the bowl was to the right and the right hand is used.

The preferred and the nonpreferred hand were also determined for each child. We coded which hand (left, right, or both) was used to grasp the hand

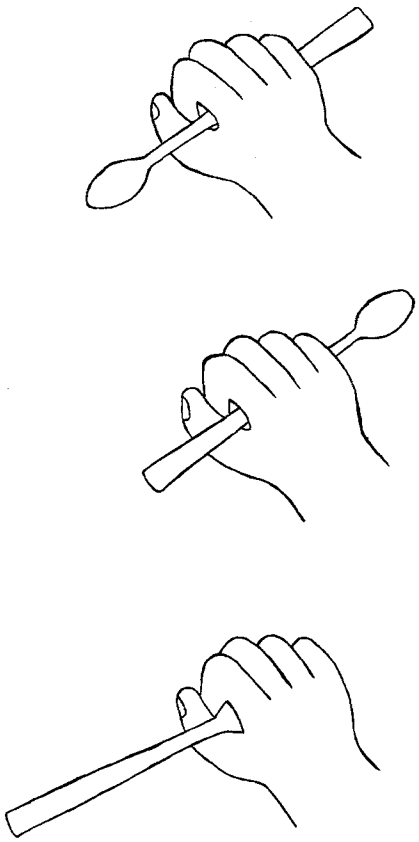

Figure 2. A sketch of the three grips: a radial grip (top); an ulnar grip (middle); and a goal-end grip (bottom).

preference items and then summed the number of reaches with each hand. There was a wide range of one-hand reaches (from two to seven) because some children used two hands for some items, and some children refused to reach for the same item more than once. Nevertheless, the hand that was used more often was considered the preferred hand. A tie occurred for 5 of the children and was broken by including the number of reaches with each hand for the toys with a handle and the spoon. The right hand was identified as the preferred hand for 31 of 36 children.

Results

Each child was presented with the spoon and the toys on a mean number of 8.1 and 9.4 trials, respectively. All of the children reached readily for both the spoon and the toys. One-hand grasps were used on almost all trials (n = 579, or 92% of total trials), and only those trials were included in the analyses. Two-hand grasps (n = 9), misses (n = 22), trials with no reach (n = 2), and trials with procedural errors (n = 18) were eliminated.

The goal end of the spoon was placed in the mouth on 91% of the total trials. Thus at the outcome level, children from each age group were successful in getting food to the mouth. In contrast, children placed the goal end of the toys in the mouth on only 25% of the total trials. This indicates that although the spoon was used appropriately to transport food to the mouth, children did not place the objects into their mouths indiscriminately. Even the 9-month-olds put the bowl of the spoon in their mouth more often than the toy end of toys on handles (89% vs. 48%).

Group Data

The children who participated in this study came into this task with two strong preexisting tendencies. The first was to use the overhand orientation when grasping all items by the handle. Children used the overhand orientation for every grasp with the exception of one 19-month-old, who used the underhand orientation on one spoon trial. The second tendency was to reach with one hand more than with the other. Overall, children reached with the hand we identified as their preferred hand on 67% of toy trials and 70% of spoon trials.

Combining the children's preexisting tendencies with the experimental manipulation of changing which side the handle was on from trial to trial had dramatic effects on how the items were grasped and on how the spoon was transported to the mouth. We distinguished between trials in which the radial grip was more likely to occur and trials in which nonradial grips were more likely. *Easy trials* were those in which the handle was on the same side as the preferred hand. On easy trials, children achieved a radial grip by following their preexisting tendencies and grasping the handle with the preferred hand in the overhand orientation. *Difficult trials* were those in which the goal end was on the same side as the preferred hand: If children followed their preexisting tendencies, they would end up with either an ulnar grip (if they grasp the handle) or a goal-end grip (if they grasp the bowl of the spoon or the toy).

Three grips. The mean percentage of trials in which each of the three grips was used is shown in Figure 3 for the toys and the spoon for easy and difficult trials. The mean percentages for each item within each age group add to 100; for example, when the 9-month-olds reached for the toys on the easy trials, they used a radial grip, a goal-end grip, and an ulnar grip on 65.6%, 24.0%, and 10.4% of the trials, respectively. The data from the easy and difficult trials were analyzed separately. On easy trials, the radial grip was overwhelmingly selected among all age groups and for both types of items (see Figure 3). An analysis of variance (ANOVA), with age group as a between-subjects variable and item as a within-subjects variable, was computed on each of the three grips. The radial grip was more likely to be selected for the spoon than for the toys, $F(1, 33) = 8.63$, $p < .006$, and among older children than among younger children, $F(2, 33) = 3.64$, $p < .037$. Similarly, the goal-end grip was less likely to be selected for the spoon than for the toys, $F(1, 33) = 6.09$, $p < .019$. There were no significant effects for the ulnar grip. Thus, although the easy trials played into the preexisting tendencies of infants and led to the radial grip being overwhelmingly selected, even on these trials the radial grip was more likely to be selected for the spoon than for the toys, and among older children more than younger children.

For difficult trials, reaches for the spoon in particular revealed developmental progress in grip strategy (see Figure 3, bottom right). Whereas the 9-month-olds chose grips indiscriminately, the 14-month-olds were less likely to grasp the goal end and were most likely to use an ulnar grip on the handle. By 19 months, the radial grip was the overwhelming choice, being used on an average of 86% of the trials. An ANOVA, with age group as a between-subjects variable and item as a within-subjects variable, was computed for each of the three grips for the difficult trials. For the radial grip, there was an effect of age group, $F(2, 33) = 5.91$, $p < .007$, and an Age Group $\times$ Item interaction, $F(2, 33) = 5.52$, $p <$

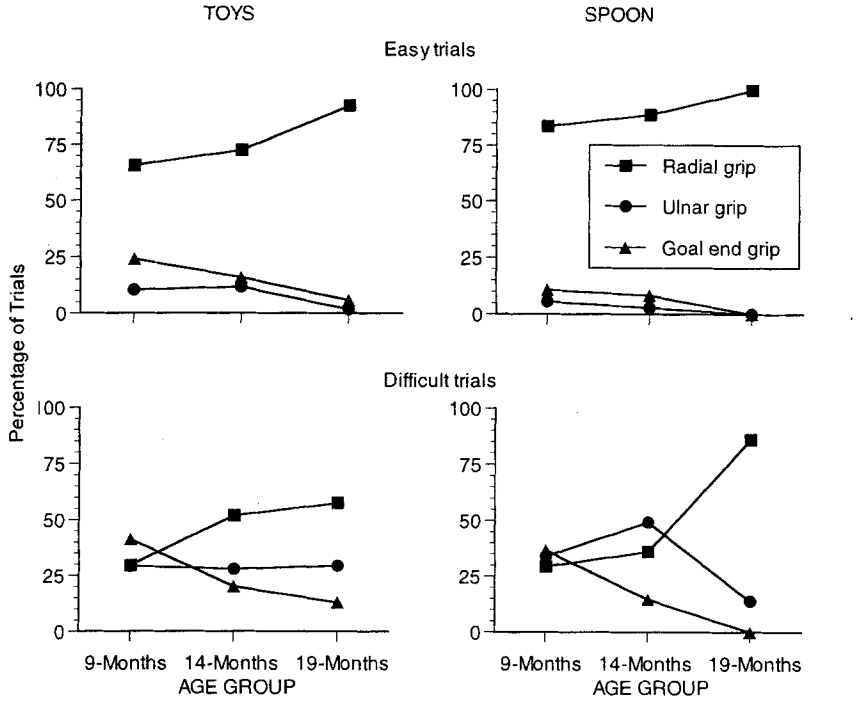

Figure 3. Percentage of reaches with each of the three grips for each age group and both the toy and spoon conditions: data from easy trials (top) and difficult trials (bottom).

.009. The radial grip was used more among older children than among younger children, and the increase was greater for the spoon than for the toys, particularly at 19 months. There was a significant decrease in goal-end grips across age, $F(2, 33) = 7.53$, $p < .002$. There was also a significant Age Group × Item interaction for the ulnar grip, $F(2, 33) = 3.47$, $p < .043$; although use of the ulnar grip remained stable for the toys, the mean value for the spoon increased from the 9- to the 14-month-olds and decreased from the 14- to the 19-month-olds.

In summary, the radial grip was used more for the spoon than toys at all ages, with the 19-month-olds showing a marked increase when they reached for the spoon. Children from this age group were successful at achieving a radial grip even in the difficult orientation.

Hand choice. It was noted earlier that children came into this task with tendencies to reach consistently with one particular hand and to use the overhand orientation. Children from the 19-month-old group had to overcome one of these tendencies to achieve a radial grip on difficult spoon trials. Although one 19-month-old successfully used the underhand orientation on one spoon trial, every other child used the overhand orientation on every relevant trial. Thus, a radial grip was achieved by suppressing the tendency to reach with the dominant hand and by alternating which hand they reached with. The data for handle-side hand use are presented in Figure 4. The lower end of the scale is set at 50%, which is the percentage achieved if a child always reaches with the same preferred hand. An ANOVA was computed with age group as a between-subjects variable and item as a within-subjects variable. The older children were more likely to reach with the handle-side hand than the younger children, $F(2, 33) = 10.45$, $p < .001$, and children were more likely to reach with the handle-side hand for the spoon than for the toys, $F(2, 33) = 4.88$, $p < .034$. The Newman–Keuls test was used to make pairwise comparisons among all of the groups for the spoon data, and 19-month-olds were found to be more likely to use the handle-side hand with the spoon than were 9- and 14-month-olds. In summary, there was a change in strategy when the 19-month-olds reached for the spoon: They inhibited reaching with their preferred hand in favor of reaching with whichever hand was on the handle side of the spoon.

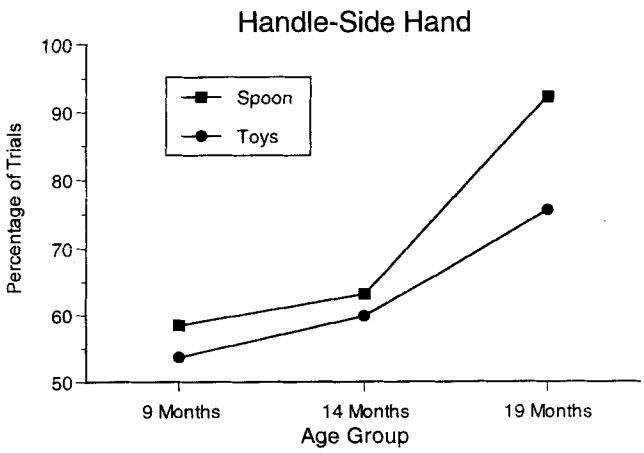

Figure 4. Percentage of reaches with the handle-side hand for the spoon and toys.

This allowed them to achieve a radial grip on difficult as well as on easy trials.

Consequences of selecting a nonradial grip. When a spoon is grasped with a nonradial grip, if a correction is not made during transport the handle will go into the mouth. In fact, the handle was first placed in the mouth on 33% of nonradial grip trials, compared with 2% of radial grip trials. On the remaining nonradial grip trials, a correction was made. The point at which a correction occurs in the sequence of actions is an indication of how far in advance of the goal state (i.e., food in the mouth) the infant is planning. The number of nonradial grips for the spoon decreased from 45 to 30 to 5 for the 9-, 14-, and 19-month-olds, respectively, which is consistent with the age-related increase in the percentage of radial grips shown in Figure 3. The number of nonradial grips in which some part of the spoon was brought to the mouth is shown in Figure 5, along with correction information.[1] The handle was first placed in the mouth on more than half of the nonradial grip trials for the 9-month-olds (i.e., 24 of 43 trials). On most of these trials (i.e., 16 of 24) they made a late correction, and eventually the bowl of the spoon was placed in the mouth. Thus, the 9-month-olds typically did not correct until *after* they had placed the handle in the mouth.

In contrast, on all of the trials in which the 14-month-olds placed the spoon in the mouth, they made a correction *before* the spoon was brought to the mouth so that the handle was never placed in the mouth. On 18 of the trials, the 14-month-olds used the same hand: They usually rotated the wrist and awkwardly placed the spoon in the mouth while still using an ulnar grip. On the other 10 trials, the 14-month-olds switched the spoon to the other hand to hold the spoon with a radial grip before it was transported to the mouth. Thus, although the 14-month-olds often began the trial with a nonradial grip of the spoon, they always corrected to get the bowl of the spoon into their mouth, and they never placed the handle in the mouth. The 19-month-olds obviated the entire problem by reaching with the hand on the handle side of the spoon to achieve a radial grip.

The duration data support these findings. The spoon-to-mouth and bowl-to-mouth durations were identical for the 14-month-olds (3.43 s) because they never placed the handle in the mouth, and they were nearly identical for the 19-month-olds (2.03 and 2.05 s). In contrast, the 9-month-olds had a very fast spoon-to-mouth duration (1.65 s) but a slow bowl-to-mouth duration (3.79 s). The distinction between the 9- and 14-month-old groups is even more apparent when radial and nonradial grip trials are separated (see Figure 6). Radial and nonradial grip trials are presented for only the 9- and 14-month-olds because the 19-month-olds had only five nonradial grip trials. (Note: only seven 14-month-olds contributed to this analysis; timer data were not available for 2 children and 3 never used a nonradial grip.) A 2 × 2 ANOVA, with age group (9 vs. 14 months) as a between-subjects variable and grip (radial vs. nonradial) as a within-subjects variable, was computed on the spoon-to-mouth and bowl-to-mouth durations. For spoon-to-mouth duration, there was a main effect for age, $F(1, 17) = 7.22$, $p < .016$, and grip, $F(1, 17) = 6.52$, $p < .021$, but the relationship was best explored in the Age Group × Grip interaction, $F(1, 17) = 7.49$, $p < .014$. The 14-month-olds were slower in bringing the spoon to the mouth following a nonradial grip than after a radial grip, whereas the 9-month-olds had similar spoon-to-mouth times for both grips (Figure 6, top). For bowl-to-mouth duration, it took longer to place the bowl of the spoon in the mouth following

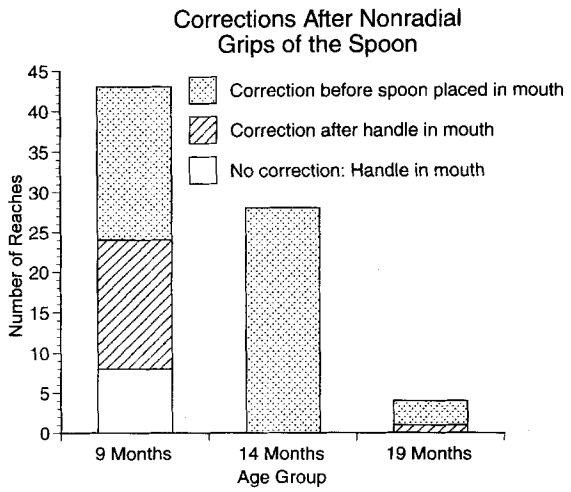

Figure 5. Corrections after the spoon was gripped with a nonradial grip (i.e., an ulnar grip or a goal-end grip).

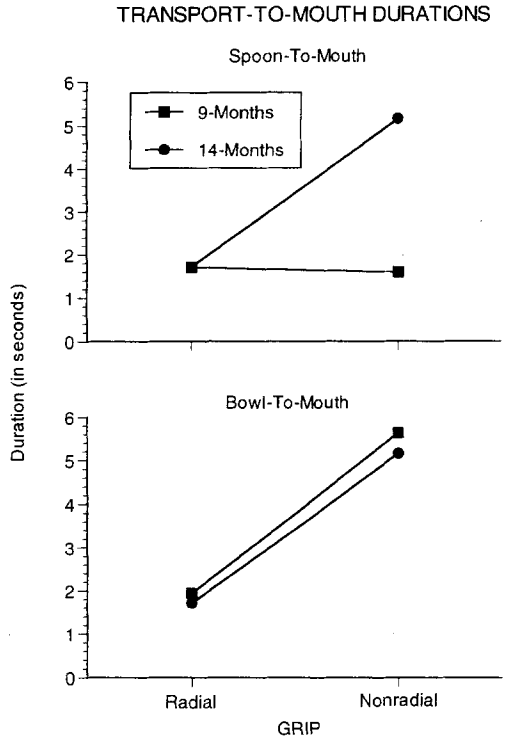

Figure 6. Spoon-to-mouth durations (top) and bowl-to-mouth durations (bottom) are shown as a function of grip. Just the 9- and 14-month-old data are shown, as nonradial grips were infrequent in the oldest children.

[1] The spoon was not brought to the mouth on every trial following a nonradial grip. It was brought to the mouth on 43 of 45 trials for 9-month-olds, 28 of 30 trials for 14-month-olds, and 4 of 5 trials for 19-month-olds.

a nonradial grip than a radial grip for both age groups, $F(1, 17) = 9.93$, $p < .006$. In Figure 6 (bottom), the penalty for a nonradial grip is clear for the 9-month-olds now, as their error correction takes an additional 3 to 4 s after the quick transport of spoon to mouth. These findings support the interpretation that the 9-month-olds did not differentiate among the grips before placing the spoon in the mouth, whereas the 14-month-olds did. When the 9-month-olds used a nonradial grip, they made a correction after finding the handle in their mouth. In contrast, 14-month-olds noticed the odd configuration of spoon and hand and corrected the problem during bowl-to-mouth transport.

Individual Data With the Spoon

The identification of strategies adopted by individual infants will help us to understand the process by which actions and their consequences were selected and managed. The group findings are used as a guide. There was an age shift from reaching with the preferred hand to reaching with the handle-side hand in the group data, so we begin by examining hand selection. Each trial was categorized along two dimensions: One dimension was the use of the preferred versus the nonpreferred hand; the other dimension was the use of the handle-side hand versus the bowl-side hand. A child's dominant reaching strategy was determined on the basis of which category had the highest number of reaches in it. To reach consistently with the handle-side hand, the child must inhibit the tendency to always reach with the same hand and instead use the right or left hand in response to the spoon's orientation.

The hand-use data are presented in Table 1 for each child. It is worth noting the within-subject variability in hand use. For example, the 9-month-olds usually reached with their preferred hand, but most of them reached with the nonpreferred hand on some trials. Siegler (1996) stressed the importance of variability in learning and development. By varying actions, the child can determine whether some other strategy might lead to a better outcome. In this situation, the child who varied hand selection may come to learn that this is advantageous rather than reaching exclusively with the preferred hand.

An examination of hand use in Table 1 reveals that almost every 9-month-old and most 14-month-olds (i.e., 8 of 12) reached predominantly with the preferred hand.[2] (Children who primarily reached with the same hand have a 1 or 2 in the Strategy column of Table 1.) In contrast, some 14-month-olds (i.e., 4 of 12) and most 19-month-olds (i.e., 10 of 12) predominantly used the handle-side hand to reach for the spoon, labeled 3 in the Strategy column in Table 1. Thus, consistent with the group data, there was a strategic shift from reaching with the preferred hand to reaching in response to the spoon's orientation. In general, this shift occurred between 14 and 19 months.

Other group differences indicated that two strategic shifts occurred between 9 and 14 months: first, the tendency to grasp the goal end of the spoon and, second, putting the handle in the mouth. Both of these behaviors were likely to occur during reaches with the bowl-side hand, and those data are also presented in Table 1. Most of the 9-month-olds and some of the 14-month-olds grasped the goal end at least once, but none of the 19-month-olds ever did. Infants have learned to use the spoon as a tool by grasping the handle rather than going directly for the food. Table 1 also shows that most of the 9-month-olds brought the handle of the spoon to their mouth at least once, but none of the 14-month-olds ever did.[3]

These last two strategic shifts—learning to grasp the handle and learning not to put the handle in the mouth—appear to be independent of each other. For example, Infant 12 always grasped the spoon by the handle but then placed the handle in the mouth. In contrast, Infant 19 would grasp the bowl of the spoon but never placed the handle in the mouth. (Children who reached with the preferred hand and who did not make either error have a 2 in the Strategy column of Table 1, whereas children who reached with the preferred hand and who did make one of these errors have a 1 in the Strategy column.) The number of infants at each age who followed these strategies are shown in Table 2. Note that there is a developmental trend in the strategies but that there is some overlap between age groups. Whereas all of the 9-month-olds engaged in the first strategy, all three strategies were used by 14-month-olds, and only the last two strategies were used by 19-month-olds.

Discussion

In this study, 9-, 14-, and 19-month-old children reached for a spoon loaded with food and for toys with handles. The items were presented at midline, but with the goal end of the items alternately presented on the child's left and right. The children consistently placed the bowl of the spoon in the mouth, indicating that the spoon was used in a goal-directed manner, whereas they engaged in no particular goal action for the toys. In general, the 9-month-olds tended to reach with their preferred hand in the overhand orientation. This strategy sometimes led to awkward grips on the spoon. They immediately placed the spoon in the mouth, which meant that the handle ended up in the mouth on trials when the goal end was on the same side as the preferred hand. The 14-month-olds also tended to reach with their preferred hand in the overhand orientation. However, they made corrections, if necessary, before transporting the spoon to the mouth so that they only placed the bowl of the spoon in the mouth and never the handle. The 19-month-olds tended to inhibit reaching with their preferred hand. Instead, they alternated hands in coordination with the spoon's orientation, reaching with their handle-side hand in the over-

[2] Two of the children (Infant 6 and Infant 16) reached predominantly with the nonpreferred hand. The hand preference for these children may have been misidentified when hand preference was assessed. Indeed, for the toys and spoon tasks combined, Infant 6 used the nonpreferred hand on 12 of 17 trials, and Infant 16 used the nonpreferred hand on 13 of 18 trials.

[3] We note that 1 of the 19-month-olds (Infant 29) also placed the handle of the spoon in the mouth one time. However, in Table 1 we see that, in contrast to the 9-month-olds who usually reached with the preferred hand, this child predominantly reached with the handle-side hand. This one instance of a 19-month-old placing the handle in the mouth is a likely result of the child's failure to attend to the orientation of the spoon on one trial, perhaps because the solution had become habitual or automatic.

Table 1
Number of One-Hand Reaches With the Preferred (P) and the Nonpreferred (NP) Hand and With the Handle-Side (H) and the Bowl-Side (B) Hand for the Spoon Trials for Each Participant

	Hand used				Bowl-side hand reach			
Infant	P	NP	H	B	Ulnar	Goal end	Handle to mouth	Strategy
				9-month-olds				
1	10	1	6	5	4	1	1	1
2	7	1	3	5	2	3	3	1
3	8	1	6	3	0	3	1	1
4	7	0	4	3	2	1	0	1
5	7	4	5	6	5	1	1	1
6	1	6	5	2	1	1	0	1
7	7	2	7	2	0	2	2	1
8	5	4	4	5	2	3	5	1
9	6	0	3	3	0	3	2	1
10	7	2	7	2	0	2	0	1
11	8	1	5	4	3	1	4	1
12	10	4	9	5	5	0	5	1
Total	83	26	64	45	24	21	24	
				14-month-olds				
13	5	0	2	3	3	0	0	2
14	4	2	5	1	1	0	0	3
15	6	0	3	3	3	0	0	2
16	2	6	2	6	1	5	0	1
17	6	0	3	3	3	0	0	2
18	3	1	2	2	2	0	0	2
19	10	0	5	5	0	5	0	1
20	9	1	5	5	5	0	0	2
21	4	5	9	0	0	0	0	3
22	4	3	7	0	0	0	0	3
23	3	4	7	0	0	0	0	3
24	5	0	3	2	1	1	0	1
Total	61	22	53	30	19	11	0	
				19-month-olds				
25	3	3	6	0	0	0	0	3
26	7	0	3	4	3	0	0	2
27	2	2	4	0	0	0	0	3
28	2	2	4	0	0	0	0	3
29	5	5	9	1	1	0	1	3
30	3	1	3	1	1	0	0	2
31	4	5	9	0	0	0	0	3
32	4	2	6	0	0	0	0	3
33	3	3	6	0	0	0	0	3
34	6	6	12	0	0	0	0	3
35	4	4	8	0	0	0	0	3
36	2	2	4	0	0	0	0	3
Total	45	35	74	6	5	0	1	

Note. For bowl-side hand reaches, values indicate the number that resulted in ulnar and goal-end grips and the number in which the handle was placed in the mouth. On the basis of this information, each child was categorized in one of three strategies. See text for details.

hand orientation to achieve a radial grip. Food could then be smoothly and efficiently transported to the mouth.

Reaching for a Spoon Versus a Toy

Children reached for and used the spoon differently than the toys. In reaching for the spoon, children were more likely to use a radial grip on the handle, which is the most efficient or "correct" grip. We take this as evidence that the subsequent use of an item will influence the decision to pick it up in a certain way. In other words, we hypothesize that the difference in goals is the reason that children grasped toys and spoons differently. Spoons carried the specific goal of getting food, whereas toys had a variety of

Table 2
Classifying Children According to Their Pattern of Results for the Spoon Trials

Strategy	Age group (in months) 9	14	19
1. Grasp bowl of spoon or place handle in mouth	12	3	0
2. Grasp handle of spoon with preferred hand and place bowl in mouth	0	5	2
3. Grasp handle of spoon with the handle-side hand in a radial grip and place bowl in mouth	0	4	10

uses, such as visual examination and haptic exploration. These latter goals led children to reach more often directly for the toy itself, or goal end, compared with spoon trials. In this regard, all age groups let an item's future use influence their reach and grasp. Without the toy data, we would not know whether the children picked up items indiscriminately, without regard to their purpose. The contrast between spoon and toy grips suggests that goals guided the children's choice of actions with the item. Because the spoon had a definite goal, strategies involving sequential action emerged more clearly, and we examined those actions in more detail.

Developmental Changes in Reaching for the Spoon

A model of the development of planning. In examining group and individual data, we identified several recurring strategies that the children used to solve the spoon problem. We model action-selection strategies in this task and consider this to be a demonstration of the development of action plans in children younger than 2 years. The purpose of presenting a specific model is that it can generate new research to evaluate the predictions that are made from the model.

Four strategies are included in this model of the development of action plans (see Figure 7). Characteristics of each strategy are presented as well as reasons why a particular strategy may be selected at one time and abandoned at a later time. The model makes two assumptions: (a) The child is motivated to predict the consequences of his or her actions on the environment, and (b) the child is motivated to find efficient solutions (see Rosenbaum & Jorgensen, 1992), and the standard of efficient action becomes more stringent with age.

Initially, this task is under feedback control. The child follows his or her preferences until a situation is produced in which the child can evaluate whether the goal has been achieved. At first, the child perceives the spoon with food and reaches for it with the preferred hand. Orientation of the spoon and perhaps even the handle are not taken into account. If the handle of the spoon winds up in the mouth, this requires a correction. This strategy probably works well in the home environment: If the parent always presents the handle on the same side as the child's preferred hand, then no corrections are necessary.

In the partially planned strategy, the transport-to-mouth component is planned but not the grasp component. The child reaches with the preferred hand but then notices the location of the bowl of the spoon with respect to the hand. If the bowl of the spoon is on the outside part of the hand (i.e., the spoon is held with an ulnar grip), then the child must make a correction during transport. One difference between this and the preceding strategy is that the child has differentiated the relationship of the parts of the spoon in terms of the goal and no longer grasps the bowl. This important advance signifies that the child now uses the spoon as a tool to convey food to the mouth. A second difference is that the child has inhibited a preference to bring the item immediately to the mouth, which allows for mid-reach corrections. This is an effective strategy with respect to outcome, but the process is inefficient because a correction must be made every time the spoon is grasped with an awkward grip.

In the next strategy, the sequence of actions is fully planned. For the first time the orientation of the spoon affects planning of the reach, hence, perception of orientation is now placed before the reach (see Gibson, 1969). The child evaluates the current position of the spoon with respect to the goal state and solves the problem of getting the bowl of the spoon to the mouth in thought before grasping the spoon. The child's solution is to grasp the handle of the spoon with a radial grip (i.e., the handle-side hand in the overhand hand orientation), even when this requires the use of the nonpreferred hand. This is an efficient strategy with respect to action. However, it may require thought (i.e., means–ends problem solving) on every trial.

The final strategy occurs after the crucial insight for solving the problem has been determined. The solution on every trial is to grasp the spoon with a radial grip, and this has become a heuristic. Once the strategy has been generalized into a heuristic, the problem does not need to be solved on each trial, and the perception–action sequence does not need to be monitored as carefully as before.

Connecting the model to the literature. This model is consistent with De Lisi's (1987) developmental taxonomy of plans. De Lisi presented four types of plans, three of which are found in this model. The feedback-based strategy is a Type 1 plan (i.e., a "plan in action"). In a Type 1 plan, a sequence of behaviors is performed to achieve a goal (i.e., to eat food); the goal may have been imposed or triggered by the presentation of the food. There is no symbolic representation in a Type 1 plan, nor does the child engage in planning in any of its phases. The child is only aware of success or failure at goal attainment. The partially planned and fully planned strategies are Type 2 plans (i.e., "plans of action"). In a Type 2 plan, there is a deliberate sequencing of behaviors to facilitate goal attainment. Plans are present, but only in a short-term context that involves a real situation. Plan formation occurs immediately before plan execution; that is, the two phases of planning are differentiated but temporally contiguous. In the partially planned strategy, plan formation occurs after the spoon is grasped but before it is transported to the mouth. In the fully planned strategy, plan formation occurs immediately before the spoon is grasped. The final strategy may be a Type 3 plan (i.e., a "plan as a strategic representation"). Type 3 plans are not restricted to the immediate context. Rather, there is a deliberate, strategic representation of anticipated future states of the environment along with behavior sequences to deal with them. The child recognizes that a plan is needed and useful, and this recognition leads to plan formation. Plan formation and execution are completely differentiated, hence, the two phases of planning are no longer temporally contiguous. Because plan execution is independent of plan forma-

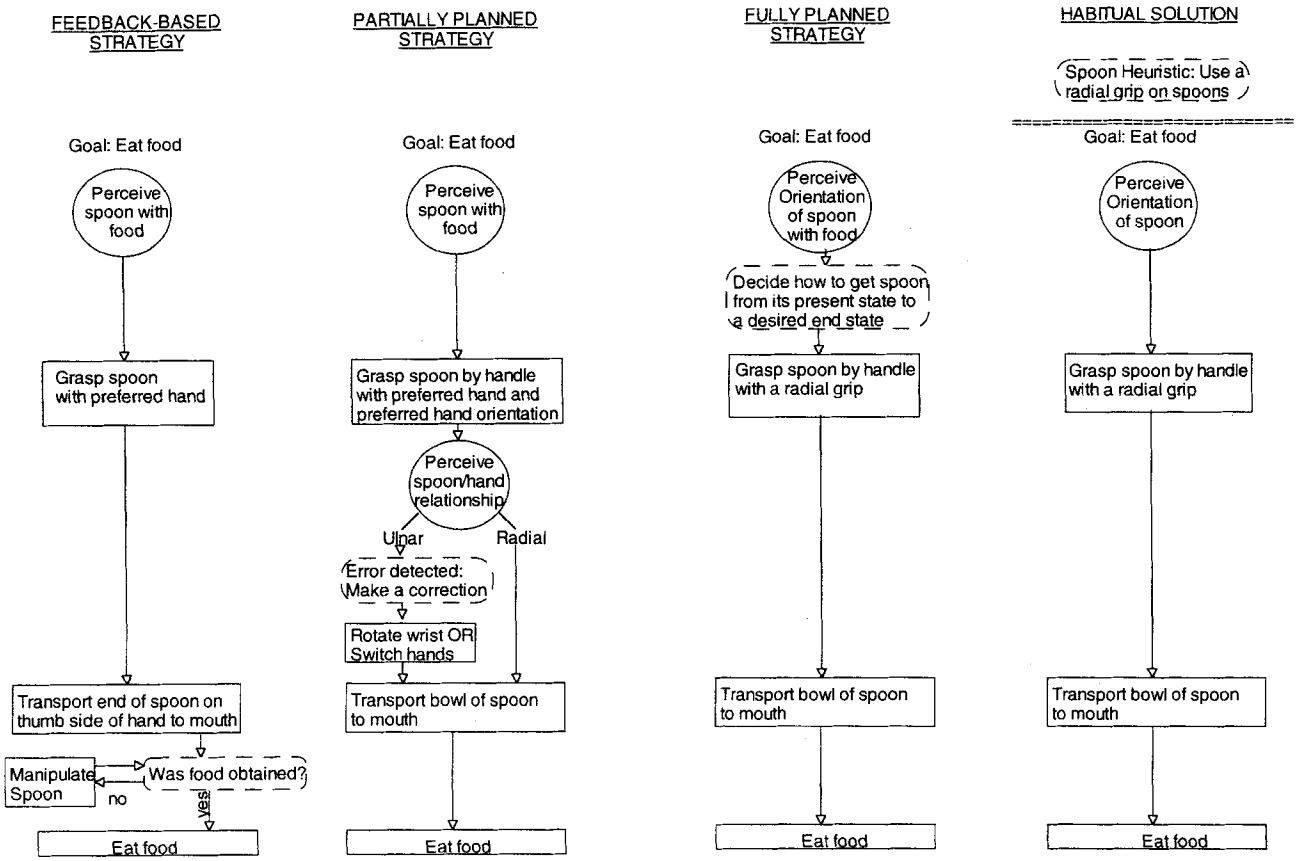

Figure 7. A four-stage model of the development of planning when reaching for the spoon in this situation. Circles represent perception, solid boxes represent action, and dashed boxes represent thought processes.

tion, the execution phase of a Type 3 plan differs from the execution phase of the other strategies. Specifically, the task has changed from a means–ends problem to a reproductive problem (Covington, 1987). In a means–ends problem, the problem is specified, the end state is known, but the plan of action is not known. In a reproductive problem, all three aspects are known. That is, the problem is specified, the plan of action is known, and the end state is known. The child simply selects a radial grip each time the spoon is presented. There is no planning on individual trials, as a habitual solution is used rather than a deliberate solution (Rogoff, Gauvain, & Gardner, 1987).

Evaluating the model. Future research could be directed toward evaluating predictions made by the model. One prediction is that children will be slower during certain actions depending on their current strategy level. Specifically, the transport-to-mouth action should be slowest for children using a partially planned strategy because they are evaluating their options after the spoon has been grasped. A second prediction is that time to grasp should be slowest for children in the fully planned strategy because they are evaluating their options before reaching for the spoon. There is some support for the first prediction in the transport-to-mouth duration data. The spoon-to-mouth durations for the ulnar grip show that the 14-month-old group was slower than the 9-month-old group (see Figure 6). This prediction seems counterintuitive because one would expect more efficient transport-to-mouth durations with increasing age owing to better motor control over arm and hand. The fact that 14-month-olds, in comparison with 9-month-olds, actually slowed down is suggestive of mental operations that changed the ongoing action plan. The experiment was not designed to provide accurate data concerning the second prediction. One would have to conceal the item until it was within reach, then measure latency to grasp. The child had several seconds to observe the experimenter setting up the items on the holder, after which the holder was slowly pushed forward to within the child's reach. This observation period was long enough to wash out any differences in latency once the item was within reach.

In other work on problem-solving in young children, DeLoache and colleagues (DeLoache & Brown, 1987; DeLoache et al., 1985) concluded that there are common features across different tasks as children learn to solve problems. Initially, children detect a single element that does not fit and concentrate on that element as producing the problem; for example, in a series of nesting cups, they try to force a bigger cup into a smaller one. Later they consider the context of the nonfitting element; to continue the seriated cup example, they make a "local correction" by seeking a new cup when one does not fit into another. Finally, children consider the entire problem set and the internal relations among the elements within it. There is a nice parallel between this developmental progression described for preschoolers and older children and the model we proposed. For example, quickly placing the

spoon in the mouth and then making a correction if necessary is similar to detecting a single nonfitting element and fixing that. When children corrected a nonradial grip before placing the spoon to the mouth, they considered the context of the problem, in this case the orientation of the spoon in relation to the hand and the mouth. Finally, noting the orientation of the spoon and reaching so as to achieve a radial grip involve considering the entire problem set and noting the relationship of the spoon to the body in advance. We consider this last phase to be the precursor of reasoning and thinking about problems, as did DeLoache and Brown (1987).

In conclusion, it is difficult to study planning in young children because of their limited verbal abilities. Arguably the best way to study this area is through observing goal-directed behavior. The action-selection research presented in this article enabled us to infer alternative ways of thinking and planning in very young children. The proposed model of the development of planning documents a shift in when children evaluate a sequence of actions. At first, the sequence of actions is evaluated after all of the actions are executed, then the evaluation occurs in the middle of the action sequence, and eventually the action sequence is evaluated prior to overt action. This last step is a significant achievement in planning behavior because it is the only one that avoids the necessity of correcting errors. The model documents the evolution of planning ahead during the 2nd year of life as the child comes to master the earliest tool our culture demands.

References

Adolph, K. E. (1997). Learning in the development of infant locomotion. *Monographs of the Society for Research in Child Development, 62* (3, Serial No. 251).

Brown, A. L. (1990). Domain-specific principles affect learning and transfer in children. *Cognitive Science, 14,* 107–133.

Bruner, J. S. (1981). Intention in the structure of action and interaction. In L. P. Lipsitt (Ed.), *Advances in infancy research* (Vol. 1, pp. 41–56). Norwood, NJ: Ablex.

Connolly, K., & Dalgleish, M. (1989). The emergence of a tool-using skill in infancy. *Developmental Psychology, 25,* 894–912.

Covington, M. V. (1987). Instruction in problem solving and planning. In S. L. Friedman, E. K. Scholnick, & R. R. Cocking (Eds.), *Blueprints for thinking* (pp. 469–511). New York: Cambridge University Press.

De Lisi, R. (1987). A cognitive–developmental model of planning. In S. L. Friedman, E. K. Scholnick, & R. R. Cocking (Eds.), *Blueprints for thinking* (pp. 79–109). New York: Cambridge University Press.

DeLoache, J. S., & Brown, A. L. (1987). The early emergence of planning skills in children. In J. Bruner & H. Haste (Eds.), *Making sense: The child's construction of the world* (pp. 108–130). New York: Methuen.

DeLoache, J. S., Sugarman, S., & Brown, A. L. (1985). The development of error correction strategies in young children's manipulative play. *Child Development, 3,* 928–939.

Gesell, A., & Ilg, F. L. (1937). *Feeding behavior of infants.* Philadelphia: Lippincott.

Gibson, E. J. (1969). *Principles of perceptual learning and development.* New York: Appleton-Century-Crofts.

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

Ramsay, D. S. (1980). Onset of unimanual handedness in infants. *Infant Behavior and Development, 3,* 377–385.

Rogoff, B., Gauvain, M., & Gardner, W. (1987). The development of children's skills in adjusting plans to circumstances. In S. L. Friedman, E. K. Scholnick, & R. R. Cocking (Eds.), *Blueprints for thinking* (pp. 303–320). New York: Cambridge University Press.

Rosenbaum, D. A., & Jorgensen, M. J. (1992). Planning macroscopic aspects of manual control. *Human Movement Science, 11,* 61–69.

Rosenbaum, D. A., Marchak, F., Barnes, H. J., Vaughan, J., Slotta, J. D., & Jorgensen, M. J. (1990). Constraints for action selection: Overhand versus underhand grips. In M. Jeannerod (Ed.), *Attention and performance XIII: Motor representation and control* (pp. 321–342). Hillsdale, NJ: Erlbaum.

Rosenbaum, D. A., van Heugten, C. M., & Caldwell, G. E. (1996). From cognition to biomechanics and back: The end-state comfort effect and the middle-is-faster effect. *Acta Psychologica, 94,* 59–85.

Rosenbaum, D. A., Vaughan, J., Barnes, H. J., & Jorgensen, M. J. (1992). Time course of movement planning: Selection of handgrips for object manipulation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 1058–1073.

Rosenbaum, D. A., Vaughan, J., Jorgensen, M. J., Barnes, H. J., & Stewart, E. (1993). Plans for object manipulation. In D. E. Meyer & S. Kornblum (Eds.), *Attention and performance XIV: Synergies in experimental psychology, artificial intelligence, and cognitive neuroscience* (pp. 803–820). Cambridge, MA: MIT Press.

Siegler, R. S. (1996). *Emerging minds.* New York: Oxford University Press.

Willatts, P. (1990). Development of problem solving strategies in infancy. In D. F. Bjorklund (Ed.), *Children's strategies: Contemporary views of cognitive development* (pp. 23–66). Hillsdale, NJ: Erlbaum.

Received August 12, 1998
Revision received December 29, 1998
Accepted January 7, 1999 ■