In-Hand Manipulation in Young Children: Rotation of an Object in the Fingers

Charlane Pehoski, Anne Henderson, Linda Tickle-Degnen

Key Words: gross and fine motor skills

Objective. The purpose of this study was to look at the development of two in-hand skills of rotation. Three questions were asked: (a) Do boys' and girls' performance differ significantly? (b) Does performance improve with age? and (c) Can periods of rapid improvement with age be seen on the tasks presented?

Method. The in-hand manipulation skill of rotation was measured in 154 right-handed children between the ages of 3-0 years and 6-11 years as well as in 13 adults. The participants were videotaped as they either turned over small pegs in a pegboard or rotated a peg in their fingertips. The number of pegs dropped when turning and placing them back on the board, the number of times a peg could be rotated in the fingertips, the time it took to complete each task, and the methods participants used to accomplish the two tasks were recorded from the videotapes.

Results. The results indicated no differences between the performance of boys and girls on any of the variables studied, but performance did change with age, and periods of rapid change were identified. Further, when compared on methods used, the children did not achieve the same speed or consistency as the adult participants.

Conclusion. The development of in-hand manipulation skills of rotation involves improvement in the dimensions of speed, method, and consistency. Observation of these skills in a child can add to a therapist's understanding of the child's fine motor abilities. The variability in children's performance needs to be considered in both evaluation and treatment planning.

The ability to perform precise refined movements of the hand is an important human function because it allows manipulation and mastery of the physical world. Exner (1989) referred to a category of these movements as in-hand manipulation, defined as the adjustment of an object after grasp. She described three types of in-hand movements: (a) translation, or the movement of an object from the palm to fingers or from the fingers to palm; (b) shift, or a linear movement of an object across the fingers; and (c) rotation. She divided rotation into two parts: (a) simple rotation, where an object was rolled between the pads of the fingers, and (b) complex rotation where the object was turned 180° to 360°, and the action required independent movements of the fingers and thumb.

Improvement in object manipulation is a common goal in pediatric occupational therapy. Ninety-one percent of respondents to a survey of practicing pediatric occupational therapists used object manipulation as a
treatment area several times a week (American Occupational Therapy Association, 1988). McHale and Cermak (1992) found that 30% to 60% of an elementary school day is devoted to fine motor activities. Case-Smith (1996) reported that in-hand manipulation skills improved in children when measured before and after occupational therapy intervention. She also found that scores on standard assessments were less sensitive to change. Since Exner (1989) presented her classification of in-hand manipulation movements, many studies have explored this area of performance in children (Case-Smith, 1991, 1993, 1995a, 1995b, 1996; Exner, 1990a, 1990b, 1992; Humphrey, Jewell, & Rosenberger, 1995; Jewell & Humphry, 1993), but none has clearly described how children without disabilities perform these tasks or how adults perform them.

By 3 years of age, most of the children in Exner's (1990a) study demonstrated all in-hand skills if stabilization of another object in the hand was not required. However, although children as young as 3 years of age may successfully move an object within the hand, it is not known whether the methods they use differ from those older children or adults use. Furthermore, they may be more variable in their performance, may drop more objects in the process, and may be less efficient.

The ability to manipulate an object in the hand is needed for many functional tasks, including buttoning, writing, and handling coins or other small objects. These activities require that the fingers move independently from each other and that the grip of the object be sufficient to keep it from dropping yet light enough to allow the object to be manipulated. Some of the mechanisms controlling these functions are known to mature during childhood (Evans, Harrison, & Stephens, 1990; Forsberg, Eliasson, Kinoshita, Johansson, & Westling, 1991). A better understanding of how children without disabilities perform these complex, in-hand movements and how this performance might differ from mature patterns would assist therapists in evaluating and planning programs for children with fine motor delays.

This study was designed to look at in-hand manipulation in children without disabilities ages 3-0 to 6-11 years. A sample of adults was also evaluated to obtain a measure of mature in-hand manipulation skills. Of particular interest was the participants' ability to perform the manipulative movements necessary to rotate an object in the fingers and how the performance parameters of the movement changed with age. The study questions were:

1. Do boys' and girls' performance differ significantly?
2. Does performance improve with age?
3. Can periods of rapid improvement with age be seen on the tasks presented?

Method

Participants

This study used a convenience sample of children between 3-0 and 6-11 years of age. The children were recruited from nursery schools or after-school programs located in suburban middle-class or upper-middle-class communities in Boston. Children whose parents returned a signed consent form were entered into the study. Only the results of the 154 right-handed children evaluated during the study period are reported here. Results from the left-handed children were not included because preliminary analysis indicated that they may comprise a more variable population. The children were divided into eight age groups of 6-month intervals (e.g., 3-0 to 3-5, 3-6 to 3-11, 4-0 to 4-5). For convenience, the groups will be referred to as the 3-0, 3-6, 4-0, 4-6, 5-0, 5-6, 6-0, and 6-6 groups rather than continuing to include the age range within the groups. The 3-0 through 5-0 groups each consisted of 10 boys and 10 girls. The 6-0 group contained 9 boys and 9 girls, and the 6-6 age group contained 8 boys and 8 girls. Thirteen right-handed adults (4 men, 9 women) were also recruited from the first author's place of work, the majority being human service personnel (e.g., social workers, psychologists, teachers) and ranged in age from 28 to 39 years.

Instrument

Pegs and a pegboard were chosen to elicit in-hand manipulation skills of rotation. The pegboard measured 6 in. square and was made of clear plastic. It contained 10 rows with 10 holes in each row with approximately .25 in. between the holes. The pegs were five different colors and measured .25 in. by .75 in. A small "happy face" sticker was glued to the top of each peg to help facilitate instructions to the children and to make the task a game.

Procedure

The participants were seen individually within their school or work setting. All the children readily participated in the tasks and seemed to enjoy the "games." Handedness was determined by asking all the participants to complete a drawing task. Because the purpose of this study was to observe the participant's ability to manipulate a small object in the fingers of one hand, substitute movements by the nonpreferred hand were discouraged by having them hold a wooden dowel that stood vertically on the table.

To facilitate analysis of the participants' performance, their hands were videotaped, with the focus on the thumb and radial fingers. The first author completed all scoring from the videotape without knowledge of the children's ages. A total of five in-hand manipulation tasks...
were presented. Average testing time for all five tasks was about 10 min, including the drawing task. Only the results of the rotation task and the multiple rotation task are reported here; results of the translation tasks will be reported in a separate article.

Test administration. For the rotation task, the pegboard was placed at the participant’s midline, with five pegs in the row closest to the participant and five pegs in the row closest to the examiner, who sat across the table. An empty hole was left between each peg to facilitate grasp. The rotation task was presented twice, and only the second trial was scored. If during testing, the child attempted to assist in the rotation of the peg with the non-preferred hand, he or she was reminded to hold the dowel. When necessary, the examiner encouraged grasp of the dowel by lightly placing a finger on the participant’s hand.

The examiner began by turning a peg over saying that the “man” wanted to stand on his head. The participant was then encouraged to turn over the remaining four pegs. The examiner then indicated that the man did not want to stand on his head anymore and would like to be turned back. The participant was then told to rotate the five pegs back to their original position. The instructions were repeated for the second row of pegs.

For the multiple rotation task, the examiner picked up one of the pegs and turned it over and over in the radial fingers while indicating that the man wanted to do somersaults and encouraging the participant to help him do as many as he could. A 180° turn was considered 1 rotation, and the participant was stopped after 10 rotations. If the participant could not complete 10 rotations, another trial was given, and the best of the two trials scored. During the children’s attempt to rotate the peg, the examiner lightly held the forearm in mid-position to facilitate the view of the radial fingers for later analysis of the videotape.

Determining method categories. The adult participants’ rotation methods were determined first. This determination was easy because all used the same method on the rotation task, and all but one used the same method on the multiple rotation task. To determine the children's methods, a sample of videotapes was viewed, and each completed rotation that differed from the adult sample was described. A second sample of tapes was then scored to refine the categories. This continued until the list represented all actions demonstrated by the children. With this procedure, three method categories were defined for each task. For the rotation task, the methods were the following:

1. Adult method. The participant picked up the peg between the thumb and index finger and then “pulled” it with the middle finger to begin the 180° rotation. He or she then transferred the peg to the thumb and middle finger, and the rotation was completed by a “push” movement of the index finger. All the adult participants used this method.
2. Internal rotation. The arm was internally rotated so that when the peg was picked up and the arm “de-rotated,” the peg was partially turned, and minimal finger movements were needed to position the peg correctly into the board.
3. Use of surface or other hand. A combination of two different attempts to stabilize the peg was used. One was to stabilize the peg against a surface during the rotation: against the table; the pegboard; or, more often, the chest. The other was to use the left hand. In both these instances, a structure external to the manipulating hand was used to support the action.

For the multiple rotation task, the component that seemed to most distinguish the children’s performance from the adults was the portion on the finger surface against which the peg was pivoted during rotation. All but one of the adult participants pivoted the peg against the distal phalanx of the middle finger. With the children, this pivotal point was often more proximal. For the multiple rotation task, the methods were the following:

1. Distal. The pivotal point of the peg was maintained against the distal phalanx of the finger.
2. Middle. The peg was pivoted against the middle phalanx.
3. Proximal. The peg was pivoted below the middle phalanx, including the palm of the hand.

Another aspect of the children’s performance on the multiple rotation task that differed from the adults’ was the inclusion of the ulnar fingers in the rotation process, which generally consisted of pivoting the peg against the distal surface of the ring finger instead of the middle finger.

To compute interrater reliability for the method categories on both tasks, two occupational therapists trained in recognizing the categories viewed a composite tape of 16 children randomly selected from the different age groups. The two therapists’ and first author’s scoring were compared with a coefficient of agreement, or Cohen’s kappa (Cohen, 1960; Kvalseth, 1989). The average interrater coefficient was .81 for the rotation task methods and .88 for the multiple rotation task methods.

Scoring. Three aspects of the rotation task were scored: (a) the time in seconds that it took to turn over the 10 pegs (timing began the moment the participant placed his or her fingers on the first peg and continued until the last peg was in the board); (b) the number of pegs dropped; and (c) the percentage of times each method was used when completing the task.
Additionally, three aspects of the multiple rotation task were scored: (a) the number of rotations completed in the best of the two trials; (b) time in seconds for 10 rotations, if 10 were completed (timing began the moment the participant began to turn the peg until 10 rotations were completed); and (c) the percentage of times each method was used in completing the task, including the number of rotations involving the ulnar fingers.

Data Analysis

Two-way analyses of variance (ANOVAs) were done to find the difference between the performance of boys and girls as well as between the age groups. Linear contrast analyses were completed for each dependent variable in order to address the more focused question of whether performance increased or decreased linearly with age (Rosenthal & Rosnow, 1991). To determine possible periods of rapid change in performance between age groups, independent *t* tests were done on the scores of adjacent groups. Finally, effect sizes were calculated for both the linear contrast analyses and the *t* tests. The effect size (*r*) measures the magnitude or strength of the relationship between the independent variable (age) and the dependent variables and adds information beyond that provided by significance testing (Cohen, 1988; Ottenbacher, 1986; Rosenthal & Rosnow, 1991). An *r* of .10 is considered to be a small relationship, .30 a moderate relationship, and greater than or equal to .50 a large relationship (Cohen, 1988).

Results

Two-way ANOVA procedures (with age and gender as the independent variables and the components studied for each task as the dependent variables) found no significant gender or age–gender interactions for the variables. Therefore, the results reported here relate to changes in age only.

Rotation Task

Time. There was a strong linear relationship between age and time scores, *F*(1, 138) = 114.82, *p* < .01, and the effect size (the strength of the linear relationship) was large, *r* = .67. Figure 1 shows the mean time score for each age group. Of interest was whether the more rapid changes in the slope of the time scores demonstrated by the younger groups were significant. *T* tests between the mean time scores of adjacent age groups showed significant changes with age in the younger age groups. The participants in the 3-6 group were significantly faster than those in the 3-0 group, *t*(38) = 2.42, *p* = .02, and the mean for the participants in the 4-0 group was significantly faster than for those in the 3-6 group, *t*(38) = 2.07, *p* = .05. The magnitude of the difference between both pairs (*r* = .35 and .32, respectively) was moderate. Other differences between adjacent age groups were small and nonsignificant.

Despite the decrease with age in the amount of time to complete the task, the oldest age group was significantly slower than the adult group, *t*(27) = 3.88, *p* = .0006, and the magnitude of the difference was large, *r* = .60. Therefore, the oldest children were far from achieving the efficiency or speed of the adult participants (see Figure 1).

There was a great deal of variability in the performance of the younger age groups. For example, the difference between the fastest and slowest participant in the 3-0 group was 82 sec (*SD* = 18.25), whereas the difference between the fastest and slowest participant in the 6-6 group was only 12 sec (*SD* = 3.40). It should also be noted that in every age group, except 3-0, at least one participant at each age scored within the range of the adult sample (see Table 1).

Dropping pegs. The linear contrast analysis for the number of pegs dropped was not significant. Dropping multiple pegs on this task was not a common finding. The mean number of pegs dropped was less than 1 for all age groups, and 45% to 89% of the children in all age groups did not drop any pegs. Only 15 children (10% of the total sample) dropped two pegs, and 1 child dropped three pegs. None of the adult participants dropped pegs during this task.

Methods used. With increasing age, there was a linear increase in the use of the adult method, *F*(1, 138) =

![Figure 1. Range and mean time scores on rotation task. Note. Standard deviations for the time scores, from the 3-0 group to adult group, were as follows: 18.23, 12.24, 8.54, 4.78, 6.70, 6.22, 5.99, 3.40, and 2.27.](image)
Table 1
Percentage of Children With Time Scores Within the Range of the Adult Scores on the Rotation Task

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Time Scores in Range of Adults (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-0</td>
<td>6</td>
</tr>
<tr>
<td>3-6</td>
<td>5</td>
</tr>
<tr>
<td>4-0</td>
<td>5</td>
</tr>
<tr>
<td>4-6</td>
<td>5</td>
</tr>
<tr>
<td>5-0</td>
<td>10</td>
</tr>
<tr>
<td>5-6</td>
<td>30</td>
</tr>
<tr>
<td>6-0</td>
<td>39</td>
</tr>
<tr>
<td>6-6</td>
<td>56</td>
</tr>
</tbody>
</table>

15.53, $p < .01$, a linear decrease in use of surface or other hand, $F(1, 138) = 17.50$, $p < .01$, and no significant linear change for internal rotation. The strength of the relationship of age and use of the adult method ($r = .32$) and the surface or other hand method ($r = .34$) was moderate.

Figure 2 illustrates the mean percentage of times each rotation task method was used. The adult method was most commonly used, and use increased with age. An abrupt change from use of surface or other hand to the more mature adult method can be seen for the 4-0 group. Participants in the 3-0 and 3-6 groups seemed to be almost equally dependent on the use of the surface or other hand method as they were on the adult method. In contrast, 4-0 group participants appeared to shift to a predominant use of the adult method (71%). The difference in the mean percentage between the 3-0 and 4-0 group on the adult method was significant, $t(38) = -2.12$, $p = .03$, and of moderate magnitude, $r = -.34$.

All the adult participants used the same method, which was rotating the peg in the distal fingers. The methods the children used were more varied. But consistency increased with age (see Table 2).

Multiple Rotation Task

Number of rotations: There was a significant linear increase with age in the number of rotations completed, $F(1, 138) = 127.03$, $p = .01^2$, and the strength of this relationship was large, $r = .69$. Figure 3 illustrates the participants’ rapid improvement in performance at 4-6 years of age. The mean number of rotations for the 4-0 group was 2.65, which increased to a mean of 6.45 for the 4-6 group. This difference was significant, $t(38) = -3.54$, $p = .001$, and the magnitude of the difference was large, $r = -.50$. Another significant change appeared for the 6-0 group. The mean number of rotations for the 5-6 group was 7.25 but was 9.28 for the 6-0 group, $t(36) = -2.75$, $p = .009$, $r = -.42$. Fewer rotations were completed by participants in the 6-6 group ($M = .75$) than by those in the 6-0 group ($M = 9.28$), $t(32) = 1.96$, $p = .06$, $r = .33$.

Even though the number of rotations tended to increase with age, the children still were not as skilled as the adults. The 6-0 group participants (the best of the eight groups of children) were significantly different from the adult participants, $t(29) = -2.20$, $p = .04$, and the magnitude of the difference was moderate, $r = -.36$.

Continuous rotation of a peg was a difficult task for the children. Fifty-three percent of the 3-0 group did not rotate the peg even once, and no participant in the 3-0 and 3-6 groups completed 10 rotations (see Table 3). Not until 5 to 6 years of age did every participant accomplish at least one rotation. Even in the 6-0 and 6-6 groups only 50% to 67% were able to complete 10 rotations.

Time: For the 43 children who were able to complete 10 rotations, there was no significant linear trend in the time taken to complete this task. The mean time scores ranged from 19.0 sec for the 4-6 group ($SD = 6.55$) to 15.25 sec for the 6-6 group ($SD = 4.65$). The adult participant’s mean time was 8.38 sec ($SD = 1.94$). A $t$-test comparison of the fastest group (i.e., 6-6) with the adult group indicated a significant difference in time scores, $t(29) = 4.05$, $p = .0001$, and the magnitude of this difference was large, $r = .65$. As in the rotation task, the children demonstrated more variability in their scores than did the adult participants.

Methods used. Performing multiple rotations with a small peg proved to be very difficult for the children, and the methods scores were found to be related to both the number of rotations and age. For example, a participant

---

2The contrast weights for the number of rotations on the multiple rotation task: $-7, -5, -3, -1, +1, +3, +5,$ and $+7$.
Table 2
Percentage of Participants Using Two or More Methods on the Rotation and Multiple Rotation Tasks

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Rotation Task</th>
<th>Multiple Rotation Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>n (%)</td>
</tr>
<tr>
<td>3-0</td>
<td>20 (75)</td>
<td>4 (25)</td>
</tr>
<tr>
<td>3-6</td>
<td>20 (65)</td>
<td>10 (20)</td>
</tr>
<tr>
<td>4-0</td>
<td>20 (55)</td>
<td>10 (70)</td>
</tr>
<tr>
<td>4-6</td>
<td>20 (45)</td>
<td>17 (65)</td>
</tr>
<tr>
<td>5-0</td>
<td>20 (40)</td>
<td>16 (56)</td>
</tr>
<tr>
<td>5-6</td>
<td>20 (35)</td>
<td>10 (70)</td>
</tr>
<tr>
<td>6-0</td>
<td>20 (22)</td>
<td>18 (50)</td>
</tr>
<tr>
<td>6-6</td>
<td>20 (13)</td>
<td>14 (56)</td>
</tr>
<tr>
<td>Adult</td>
<td>13 (0)</td>
<td>13 (0)</td>
</tr>
</tbody>
</table>

*Only children who were able to rotate the peg two or more times were included in these figures.*

Table 3
Percentage of Participants Completing Ten Rotations and Percentage Unable To Rotate the Peg One Time on the Multiple Rotation Task

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Completing Ten Rotations</th>
<th>Unable To Complete One Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-0</td>
<td>0</td>
<td>53</td>
</tr>
<tr>
<td>3-6</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>4-0</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td>4-6</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>5-0</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>5-6</td>
<td>45</td>
<td>0</td>
</tr>
<tr>
<td>6-0</td>
<td>67</td>
<td>0</td>
</tr>
<tr>
<td>6-6</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>Adult</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

*Best of two attempts.*

might use the distal method for one to two rotations and then drop the peg, receiving a low rotation score but a high method score. Another participant might keep the rotations going, achieving a higher rotation score but a low method score. Because of this finding, the data are presented descriptively.

Figure 4 shows the mean percentage of times each method was used. Table 4 presents the percentage of times the ulnar fingers were used. Participants in the youngest three age groups had the most difficulty rotating the peg; many could not rotate the peg at all and were not included in the method scores. When these participants were successful with one rotation, they often used the distal method. The method scores of these participants appeared to be quite good, but only the most dexterous children are represented (see Table 5).

A major change in the number of rotations occurred in the 4-6 and 5-0 groups. In these groups, the participants tended to rely on both the distal and the middle method. Apparently, these participants were better able to maintain the rotation of the peg, but they could not also maintain the peg on the distal finger surface. Starting in the 5-6 group, an increase in the use of the distal method was seen, but at this age, the participants also increased use of their ulnar fingers, which possibly supports the move to a more distal method (see Table 4).

As in the simpler rotation task, the children’s performance differed from that of the adults in the consistency of methods used. All adults used the distal method except for one who used the middle method for all 10 rotations. In contrast, many of the children used two or more methods (see Table 2).

Discussion

In answer to the three study questions, no significant differences were found between boys and girls on any of the variables studied. However, the performance of the chil-

Figure 3. The mean number of rotations completed on the multiple rotation task. Note. Standard deviations for the number of rotations, from the 3-0 group to adult group, were as follows: 1.93, 2.28, 2.33, 3.60, 3.52, 2.93, 1.18, 3.07, and 0.00.

Figure 4. Percentage of successful rotations with each method on the multiple rotation task. Note. Percentages were based on the number of times the participants rotated the peg. Only participants who rotated the peg at least once were included. Therefore, the percentages, from the 3-0 group to 5-0 group were as follows: 45%, 75%, 65%, 90%, 90%. The remaining groups included 100% of the participants.
on the Multiple Rotation Task

The children did change in a linear direction with age, and improvement was greater at some ages than at others.

The 3-year-old participants were markedly slower than their older peers. Furthermore, they had more difficulty rotating a peg without the use of an external surface for support, and, with few exceptions, the ability to rotate a peg was not a skill of 3-year-olds. However, the skills improve rapidly during the fourth year of life.

Humphry et al. (1995) also studied the in-hand manipulation skill of rotation in children using a pegboard task, but the pegs were of a different size than those used in the present study. Despite this difference, the authors reported similar results. They indicate that fewer than half of their 3-year-old participants rotated the peg in their fingers when positioning it in the board. The major change to using fingertip rotation in their study occurred between 4 and 5 years of age. As in the present study, their 6-year-old participants were inconsistent in rotating the peg in the fingers before placing it in the pegboard.

The children in the present study often used methods that substitute for refined finger movements. For example, on the rotation task, they stabilized the object against another surface or internally rotated the arm. On the multiple rotation task, difficulty was increased, and these substitute patterns were not permitted. In this situation, many of the younger participants could not succeed. Even when successful, they seemed to be seeking a stable base for the rotation movements either by moving the action to a proximal point in the hand or by including a broader surface for the action with the ulnar fingers.

In both activities the developmental trend was toward use of the adult method and toward consistency. The performances of the children were characterized by variability both within an age group and within an individual child. Variability has often been observed in the development of motor functions, including infant reach (von Hofsten, 1991) and the emergence of self-feeding (Connolly & Dagleish, 1989). In discussing the variability in infant and young children's motor skills, Thelen (1989) suggested that what is stable in the children's performance is some defined goal, but many different solutions are possible, depending on what is appropriate to the child's maturation and situation.

Several motor actions are necessary for the hand to effectively rotate a small object. One is that the fingers and thumb move independently of each other and with enough speed to make the movements efficient. Rotation also requires the regulation of grip pressure (i.e., the ability to maintain a sufficient grip to keep the object from falling yet light enough to allow the object to be manipulated). Forssberg et al. (1991) found that when picking up an object between the index finger and thumb, children under 6 years of age, particularly those 4 years and younger, use significantly more force in gripping the object than do adults. Use of additional force when picking up an object in the fingers may decrease the dropping of items as seen in the present study. However, increased force when holding an object would make continuous manipulation in the fingers slower and more effortful. It might be more efficient to rotate the peg against the middle phalanx where it is closer to the proximal point of stability.

In completing the multiple rotation task, the children often paused or had periods when their movements were slow and "labored." They needed to readjust the peg's position because it tended to slip out of optimal position in the radial fingers. The adult participants needed no such readjustments. It has been shown that the force of a precision grip and the control of an objects "slippage" is provided by tactile information from the gripping surface (Johansson & Westling, 1984). The hand depends heavily on tactile mechanisms for efficient performance. A loss of tactile feedback through illness or injury is a considerable handicapping condition (Rothwell et al., 1982; Sanes, Mauritz, Dalakas, & Evarts, 1985). Johansson and Westling (1984) found that adults without disabilities used just enough grip force to keep a small object from falling.

Table 4
The Percentage of Participants Who Used the Ulnar Fingers on the Multiple Rotation Task

<table>
<thead>
<tr>
<th>Age Group</th>
<th>n</th>
<th>Using Ulnar Fingers</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-0</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>3-6</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>4-0</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>4-6</td>
<td>18</td>
<td>25</td>
</tr>
<tr>
<td>5-0</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>5-6</td>
<td>20</td>
<td>55</td>
</tr>
<tr>
<td>6-0</td>
<td>18</td>
<td>44</td>
</tr>
<tr>
<td>6-6</td>
<td>16</td>
<td>31</td>
</tr>
<tr>
<td>Adult</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Not all the younger children were able to perform at least one rotation.*

Table 5
Percentage of Participants Using Two or More Methods on the Multiple Rotation Task

<table>
<thead>
<tr>
<th>Age Group</th>
<th>n</th>
<th>Using Two or More Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-0</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>3-6</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>4-0</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>4-6</td>
<td>17</td>
<td>65</td>
</tr>
<tr>
<td>5-0</td>
<td>16</td>
<td>56</td>
</tr>
<tr>
<td>5-6</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>6-0</td>
<td>18</td>
<td>50</td>
</tr>
<tr>
<td>6-6</td>
<td>14</td>
<td>36</td>
</tr>
<tr>
<td>Adult</td>
<td>13</td>
<td>0</td>
</tr>
</tbody>
</table>

*Only children who were able to rotate the peg two or more times were included in these figures.*
and that the regulation of this margin of safety was under the control of tactile feedback. Receptors in the skin monitor the frictional qualities between the object and the fingers, and if slippage occurs, the grip is adjusted before it is consciously detected. Johansson and Westling also noted that the adults who used the smallest margins of safety were also thought to have the most dexterous hands.

Because tactile mechanisms regulate grip force, prevent slippage, and are critical to efficient use of the hand, it is interesting to note changes in these mechanisms with age. Evans et al. (1990) looked at the maturation of cutaneous reflexes in children's hands and found that one component of this reflex response (the second excitatory phase) was not seen until 4 years of age, then it increased steadily until 12 years of age. They also found that children who did not demonstrate this component were more likely to perform poorly on a test of rapid finger movements, thereby implicating this component of the reflex in the speed of finger movements. Therefore, 4 years appears to be the age at which changes in cutaneous reflexes as well as grip force and efficiency of finger movements have been found to improve.

Limitations

The children evaluated in this study did not represent the diversity in backgrounds typical of children in the United States. They tended to be from predominantly white middle-class to upper-middle-class communities. Further, all the children attended nursery school or after-school programs and may have been exposed to more fine motor tasks than children without these experiences. This study also used only one-sized object, and it is possible that methods would change with object size. Hand size was also not controlled among participants. This was particularly true between the size of the participant's hand relative to the size of the object handled (Newell, Scully, Tenenbaum, & Hardiman, 1989).

Although this study was successful in capturing a time in development when in-hand manipulation skills were changing, it was only a window into what appears to be a long developmental course. The age period, 3 through 6 years, would seem to be a midpoint in this development. The age when in-hand rotation is just beginning was not captured in this study, nor was the fully mature pattern consistently seen in the children. A more complete picture of the maturation of these skills needs to include children younger and older than those studied here.

This study also does not provide information about the underlying mechanisms that allow children to be faster and more consistent in their performance with age. Research has suggested the maturation of tactile mechanisms in the hand as one possible area affecting change in hand function (Evans et al., 1990), but there are other possibilities, such as hand size (Newell et al., 1989) and cognition (Exner & Henderson, 1995).

Implications for Practice

In-hand manipulation is a component skill that affects task performance in children, yet few developmental tests, even those that specifically look at hand skills, include in-hand manipulation items. Activities such as picking up pellets and placing them in a bottle or moving pegs in a pegboard require only simple grasp-release movements.

Measuring speed in completing these tasks is one means of looking at skill but does not capture the manipulative capacity of the fingers and hand. True hand skill requires manipulation. It is conceivable that a child might be able to complete a grasp-carry-release task with the hand and arm yet still have difficulty manipulating an object within the fingers or hand. Although Case-Smith (1995b) found a change in children's in-hand manipulation skills after occupational therapy intervention, she did not find changes as measured by standard fine motor assessments. It has been the first author's experience that stressing the child's manipulative abilities by requiring that tasks such as those used in this study be performed by one hand is extremely useful in demonstrating the full extent of these abilities and readily differentiates the child with problems from the child without problems.

This study demonstrated that how a child performs an in-hand manipulation task and his or her consistency of performance are important variables to consider in treatment. Another area that therapists might observe in children suspected to have fine motor delays is the number of times these children drop objects. For children without disabilities, dropping objects on a rotation task seems to be rare, and if repeated dropping of small objects is observed, poor tactile mechanisms may be implicated.

Children between 3 and 6 years of age are working toward mastery of refined hand movements. When a new skill is being learned, the movement patterns are often irregular and unstable (Kamm, Thelen, & Jensen, 1990). Connolly and Dagleish (1989) stated that skills are practiced abilities, so to achieve stability, children must practice and challenge the limits of their growing abilities. Children who are typically developing tend to seek out challenging hand skills, experimenting with a variety of methods and tasks. Children who lack efficiency in refined use of the hand may avoid fine motor activities and actually get less practice than their peers. These children need to be identified, and functional activities that are appropriate to their level of skill and interest need to be introduced. ▲

Acknowledgments

This study was completed in partial fulfillment of the first author's...
References


