Development of In-Hand Manipulation and Relationship With Activities

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Objectives. This study examines the age-related increase of in-hand manipulation, the consistency of using a manipulation strategy, and the relationship between the frequency of in-hand manipulation and activities that typically require use of intrinsic hand control.

Method. Children (N = 184) between 2 years and 7 years of age were observed during selected activities that could elicit three forms of in-hand manipulation: rotation, finger-to-palm translation, and palm-to-finger translation. The child's use of a manipulation strategy was recorded. Activities that required manipulation of objects including a spoon, buttons, and crayons were also observed.

Results. The study demonstrated that the frequency of two types of in-hand manipulation increases with age and illustrated the uneven nature of development of different types of in-hand manipulation. Even when the child had the ability, use of in-hand manipulation as a movement strategy was inconsistent. Small but significant relationships between in-hand manipulation skill and performance in selected activities were found when the effects of age were controlled.

Conclusion. On a practical level, the findings raise questions as to whether maturity of in-hand manipulation may be a factor limiting performance in the everyday activities of typically developing children.

A traditional clinical view is that fine motor skills, such as neat pincer grasp to pick up a raisin or refined release to stack blocks, are hierarchically related to adaptive function (Haley & Baryza, 1990). Consistent with this assumption, Exner (1992) and Case-Smith (1993) have suggested that poor in-hand manipulation skills could be linked to clumsiness or poorer performance of functional activities. Although a correlation between in-hand manipulation skills and activities could not be used to prove the importance of intervention that targets a fine motor component, an association between in-hand manipulation and selected activities would suggest support for working on enhancing a fine motor component in therapy. At the same time, new models of human development and a better understanding of development of motor control suggest that we should examine some basic assumptions that have guided therapy.

Proficiency in executing motor components has not been a good predictor of variance in measures of performance (Starkes, 1990). Case-Smith, Fisher, and Bauer (1989) found that measures of proximal function were modestly correlated (r = .35, p < .006) and only explained 12% of the variance of fine motor control of infants. Berninger and Rutberg (1992) found a similar level
of association between performance of isolated finger movements and the quality of writing. The amount of explained variance by measures of finger tasks might have been even smaller if these authors had controlled for the ages of the children.

Changing metamodels of development and increased appreciation of the range of factors that contribute to skilled motor performance (Lockman & Thelen, 1993) have suggested the need to examine presumptions that motor skills are the critical issue in a child's performance of more complex activities. Most occupational therapists' academic preparation in development has pulled heavily from an organismic metamodel (illustrated by the work of Gesell [1946], Erikson [1963], and Piaget [1952]). The neurotherapeutic techniques that evolved during the mid-1900s were guided by the metamodel. These techniques assumed a universal, sequential nature to motor development where immature, stereotypical movements were integrated to form the basis of more functional movement as the brain matured. Confronted with a performance delay or deficit, therapists focused on enhancing immature parts of the desired, complex movement. Although following a rigid sequence of developmental milestones is no longer endorsed, therapists continue to be encouraged to focus on components of movement (Valvano & Long, 1991). Therapists, accustomed to thinking of movement components, may assume that work on specific fine motor skills in therapy will improve adaptive, functional activities.

The assumptions that guide research in the field of human development are changing (Ford & Lerner, 1992). Dynamical systems models of motor development reflect new perspectives in motor control (Kamm, Thelen, & Jensen, 1990; Lockman & Thelen, 1993; Mathiowetz & Haugen, 1994). Changes in motor milestones are thought to be due to maturation of many different subsystems, such as somatosensory, musculoskeletal, affective organization, and cognition, rather than solely to the motor system (Heriza, 1991; Kamm et al., 1990). In addition, the purpose of the task and the context of the action are thought to influence the pattern of movement (Kamm et al., 1990; Mathiowetz & Haugen, 1994). For children, the salient aspects of the environment that determine context may be fluid and may change frequently, influencing the pattern of movement and performance from minute to minute.

In developing manipulation skills, the ability to recognize and use sensory information about the object in the hand, the planning and sequence of intrinsic hand movements, the child's hand size, and the meaning of the intended activity could each constrain fine motor ability at different times in the child's development. Thus, in a dynamical systems approach, changing one feature of the task, such as the size of the object or where it is to be placed, could affect which fine motor skill a child demonstrates. In addition, the child's perspective of the meaning of the manipulation task may change during the activity. As a result of changing context, performance would vary.

The importance of considering the interactions between the task and demonstrated fine motor skill is illustrated by Exner's (1990a, 1990b) discovery that the size of the object, nature of the instructions, and modeling of an adult all influence whether a child demonstrated an in-hand manipulation skill. In a pilot study of 90 children between the ages of 18 months and 6 years, 11 months, Exner (1990a) suggested that by 2½ years of age, more than half of the subjects demonstrated in-hand manipulation abilities at least once in three trials. From a dynamical systems perspective, how consistently the movement strategy is used may be just as important as the child's ability to perform a fine motor skill. The attraction to one manipulation strategy over another would depend on the child's ability to determine efficacy among alternative manipulation strategies.

In recognizing the importance of both the organismic and dynamical systems models in understanding development, we designed a study to address the following questions:

1. Would previous findings suggesting age-related differences of in-hand manipulation skill in preschool children be supported if a different observation protocol were used?
2. Are children consistent in their use of rotation as a manipulation strategy?
3. Is there a link between in-hand manipulation and performance in different activities incorporating intrinsic hand movement?

Method

Subjects

A convenience sample of 192 children between 2 years and 7 years of age was recruited from local day care centers or after school programs. On the basis of the work by Exner (1989, 1990a), the age group targeted for the study was preschoolers. Toddlers 18 months to 23 months old were not recruited because pilot studies indicated limited success with this age group in many of the activities used in this study. Children 6 to 7 years old were included to increase the probability of observation of consistent, skilled performance in the activities. Selection criteria included signed parental consent and age-equivalent performance on the Developmental Test of Visual Motor Integration (VMI) (Beery, 1982) no lower than 12 months below the child's chronological age. Eight subjects were dropped from analysis because of more than 12-month differences between their chronological age and VMI age-equivalence scores. The final sample was 184 subjects. Of these, 42 were 2 years old, 44 were 3 years old, 44 were 4 years old, 29 were 5 years old, and 25 were 6 years old.
The subjects were primarily white (91%) and from middle socioeconomic homes as suggested by an average of more than 16 years of maternal educational level. Fifty-one percent of the subjects were boys. Eighty-two percent were reported to usually use their right hand when eating, 11% used their left hand, and 7% (primarily among the 2- and 3-year-old subjects) were reported to eat with both hands equally.

Instrument

For this study, the second author designed and standardized materials and instructions for eight child-appropriate activities that permitted observations of in-hand manipulation skills and five activities related to performance areas (Jewell & Humphry, 1993) (see Table 1).

The first two items (Taking Turns Drawing and Candles in a Cake) were used to elicit rotation, in which the object is moved around one or more of its axes (Exner, 1992). In Taking Turns Drawing, a pen was positioned in an inverted position at midline so the object had to be turned 180° for use. The procedure was repeated five times with the pen. Then, five ¼-in. bead pegs (introduced as candles for a birthday cake) were handed to the subject one at a time in an inverted position. The subject was told to put each peg in a hole in the toy birthday cake. The frequency with which the subject spontaneously used rotation over 10 observations (five times with the pen and five times with the bead peg) was the score for the rotation subscale.

The next six items of the research protocol were selected to elicit translation, movement of an object held in the fingertips to palm, or reverse movement of the object from the palm to fingertips (Exner, 1992). In each of the items, if the subject demonstrated translation with a single object, additional objects were introduced. This aspect enabled the observation of translation with stabilization of objects in the ulnar side of the hand.

The third through fifth items were used to elicit finger-to-palm translation. The subject was told that the observer wanted to see how many objects he or she could hold in one hand. First, three dry lima beans were put on the table one at a time. The same procedure was used with five nickels and then with five ¼-in. bead pegs. The final finger-to-palm translation subscale score was the sum of beans, nickels, and pegs the subject picked up in the best of two trials with each set of objects. The subscale score for translation into the palm ranged from 0 to 13.

For the three palm-to-finger translation items, either lima beans, nickels, or pegs were used. The items—feeding a cutout picture of the Sesame Street character Cookie Monster dried lima bean “cookies,” putting nickels in the bank, and putting pegs in a board—were designed so only one object could be placed at a time. The observer demonstrated and called the subject’s attention to the finger and thumb movements used for palm-to-finger translation each time an item was introduced. One bean, nickel, or peg was placed in the palm of the subject's preferred hand. If the subject was successful in one out of two trials of palm-to-finger translation of a single object,

Table 1
Summary of In-Hand Manipulation and Complex Activity Items in the Observation Protocol

<table>
<thead>
<tr>
<th>Item</th>
<th>Description of the Observation</th>
<th>Potential Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In-Hand Item</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taking turns drawing</td>
<td>Number of times the subject used rotation to position the pen for drawing</td>
<td>0-5</td>
</tr>
<tr>
<td>Candles (pegs) in a cake</td>
<td>Number of times the subject used rotation to position the peg down to place it in the hole</td>
<td>0-5</td>
</tr>
<tr>
<td>Picking up lima beans</td>
<td>Number of beans the subject picked up and translated into the palm</td>
<td>0-3</td>
</tr>
<tr>
<td>Picking up nickels</td>
<td>Number of nickels the subject picked up and translated into the palm</td>
<td>0-5</td>
</tr>
<tr>
<td>Picking up pegs</td>
<td>Number of pegs the subject picked up and translated into the palm</td>
<td>0-5</td>
</tr>
<tr>
<td>Feeding Cookie Monster cookies (lima beans)</td>
<td>Number of beans the subject could translate from palm to fingers and place in hole (Cookie Monster's mouth)</td>
<td>0-3</td>
</tr>
<tr>
<td>Putting nickels in the bank</td>
<td>Number of nickels translated from the palm to fingers and put into the bank</td>
<td>0-5</td>
</tr>
<tr>
<td>Putting pegs in the pegboard</td>
<td>Number of pegs translated from the palm and placed in pegboard</td>
<td>0-5</td>
</tr>
<tr>
<td><strong>Complex Activities</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scooping with a spoon</td>
<td>Number of lima beans dropped with moving beans from one box to the other with a spoon and how fast the subject could do it</td>
<td>0-10 sec</td>
</tr>
<tr>
<td>Feeding Cookie Monster</td>
<td>Number of garbanzo beans dropped into mouth (hole) with an infant spoon and how fast the subject could do it</td>
<td>0-10 sec</td>
</tr>
<tr>
<td>Grasping spoons</td>
<td>Scored as immature (1), transitional (2), or mature (3) of the two items with the spoon</td>
<td>2-6</td>
</tr>
<tr>
<td>Buttoning and unbuttoning shirt</td>
<td>Number of buttons the child could button and then unbutton and the amount of time (each activity was stopped after 30 sec)</td>
<td>0-6 60 sec</td>
</tr>
<tr>
<td>Coloring in triangle</td>
<td>How well the inside was covered with color (coverage) and how far outside the lines the marks went (distance)</td>
<td>0-50</td>
</tr>
</tbody>
</table>
the number of objects placed in the palm was increased so translation with stabilization could be observed. In the three protocol items, the maximum number of objects were three lima beans, five nickels, and five pegs. The palm-to-finger translation subscale score was the total across the three activities and ranged from 0 to 13.

The child’s performance in three activities developed for this study was observed next. Christiansen (1991) has defined activities as a specific goal-oriented behavior. Measures of a child’s performance in a task such as dressing were not used because tasks are a higher level of occupation and were composed of several sequenced activities. To increase the probability of finding an association between component abilities (in-hand manipulation) and occupation, the basic level of occupation, activity, was used.

Observation and activity analysis were used to identify three typically occurring activities that required some intrinsic hand control for adult-like performance. Selection of the activities was guided by discussion of what was relevant to parents and teachers. These adults might refer a child to occupational therapy if the child were clumsy, slow, or awkward in the activity. To be consistent with how others might describe the child, performance in the activities was captured with variables that reflected ability, neatness, or time. The final activities selected were scooping with a spoon (tool use), buttoning and unbuttoning (dressing), and coloring within the lines (preacademic).

Quality of performance was translated into quantitative scores to reflect motor control, speed, or accuracy. Maturity of grasp used to hold a pen and spoon were also observed. A standardized fine motor instrument was not used because summary scores could include skills that might not require intrinsic hand movement.

Scooping with a spoon was measured by asking the subject to first scoop 10 lima beans from a 2-in. square box into a 1-in. x 2-in. plastic box and then to scoop and feed Cookie Monster 10 small cookies (dried garbanzo beans) with a baby spoon. The number of beans on the spoon was not restricted. Scoring was based on the number of beans accidentally dropped and the time it took to complete. A perfect score of zero indicated that no beans were dropped. While the subject was scooping, the observer scored the subject’s grasp on the spoon as immature, transitional, or mature. An immature grasp was noted if the subject used a palmer grasp and the thumb was not on the shaft of the spoon. Transitional grasp was recorded if the subject’s thumb was on the shaft of the spoon. Mature grasp was noted if the shaft of the spoon rested in the thumb and finger web. The score for the grasp of the spoon during the two scooping activities could range from 2 (immature grasp both times) to 6 (mature grasp in both scooping activities).

Buttoning skill was measured by the number of ½-in. buttons buttoned and unbuttoned on a shirt. To give the activity meaning, the child was told it was a prize shirt. Subjects were helped to put the shirt on and were shown the stopwatch. The observer told the subject that she was interested in how fast the subject could complete the task. Buttoning and unbuttoning time were recorded if the subject was able to complete each of the two activities in less than 30 sec. The buttoning activities were limited to 30 sec each to keep from frustrating younger subjects with limited (or no) buttoning skills. If the subject did not do all three buttons, he or she was given a score of 30 sec and the buttoning was completed by the observer. The maximum total time for both buttoning activities was 60 sec.

Coloring, a preacademic skill, was measured by having the subject color a 2-in. triangle. Coverage of area inside the triangle and how well the subject stayed within the line were scored by placing a clear template over the triangle. The inside of the triangle was divided into four equal areas. Coverage was the sum of the scores based on visual inspection of each area. The score was 0 for mature (90%-100% of the area covered), 3 for transitional control of the crayon (at least 75% of the area covered), and 5 for immature (scribbles or linear strokes cover less than half the area). The template also had lines around the triangle so the distance a line went beyond the edge of the triangle could be scored. The scores for percentage of the area covered and ability to stay within the line were summed as a general measure of coloring skill; a lower score suggested more control.

During the coloring activity and while the child was coping the circle of the VMI, the maturity of grasp was recorded. A pronated or supinated palmer grasp was recorded as immature. If the child’s grasp included the thumb on the pencil but the hand was not stabilized on the paper, a transitional grasp was scored. Mature grasp of pencil or crayon was recorded if the child demonstrated a dynamic or lateral tripod and the hand was rested on the paper so movement to color was a product of intrinsic hand movement. Some children tend to change their grasp during an activity (Schneck & Henderson, 1990). If this change occurred, the most typical grasp seen during the activity was scored. The score for grasp of the pencil and crayon ranged from 2 to 6.

Stability of measures in the research protocol was examined by observing the first 20 subjects 4 weeks after an initial observation. Test–retest reliability as reflected by Pearson product–moment correlations was .82 for rotation, .83 for translation into the palm, and .75 for translation out of the palm. The Pearson correlation between the first and second observation scores for the activities ranged from .94 for the number of buttons the child could button and unbutton to .71 for the time it took the child to complete the buttoning items. Test–retest reliability for beans dropped while scooping was .77, and the reliability of the time was .79. The total scores for the coloring activity (coverage and distance over the line) had a test–retest reliability of .90.
Procedure

Parents of the subjects were given a letter that described the study and a consent form. Signed consent forms were returned to the subjects' teachers or sent directly to one of the authors. The subjects were seen individually at the day care or after school program in an area away from their class. Efforts were made to make the subjects feel comfortable with the observer, and an appropriate subject-sized table and chair were used. The translation items of the observation protocols were presented to the subject's hand that the parents indicated the subject usually used for eating. When the parent reported that the subject used both hands equally, the hand the subject used the most for drawing in the first rotation item was targeted as the preferred hand. Directions for the VMI were those in the manual (Beery, 1982).

Interrater agreement in scoring the protocol was first established by the first two authors, who are experienced occupational therapists. Three graduate students (including the third author) assisted with data collection. All of these observers demonstrated more than 80% interrater agreement.

Analyses

A total score for in-hand manipulation was obtained by summing the three subscale scores. Frequency that the child used rotation, finger-to-palm translation, and palm-to-finger translation across the respective activities were used to establish subscale scores for these forms of manipulation. A preliminary set of t-tests revealed no significant differences in the total manipulation scores or subscale scores between boys and girls; therefore, data were pooled. One-way analysis of variance was used to compare subjects grouped according to their age in 12-month intervals. Post hoc comparison (Duncan Multiple Range Test) (Cody & Smith, 1991) was used to identify the source of significant age-group differences by comparing average scores for adjacent age groups.

The relationships between manipulation skills and scores on activities were first examined by computing correlation coefficients. Because older children would be expected to be better at manipulating a spoon, doing buttons, and coloring, the correlation coefficient could be inflated by chronological age. To understand how well measures of in-hand manipulation skills could be used to predict the variability in subjects' performance in activities, multiple linear regression was used. Age, subscale scores for rotation, and finger-to-palm and palm-to-finger translation were entered into regression analysis. Stepwise procedure was used, so the computer selected as the first variable the factor that best explained the variance of the scores on the activities (Cody & Smith, 1991). In the next step, the computer searched the remaining variables for the next best predictor of activity scores. In stepwise regression analysis, the computer repeated the search until no other variable contributed significantly to the overall regression model. Because the study was exploratory, the acceptable alpha level was set at .1. Each step of the multiple regression analysis resulted in an $R^2$ value, which is the total amount of explained variance for all variables in the model at that time. The partial correlation was the percent of explained variance contributed uniquely by the single variable that entered the model at that step.

Results

Age-Related Differences

In the analysis of variance, there was a significant age-group effect for the total manipulation score ($F[4, 177] = 44.65, p < .0001$). Post hoc comparison between the age groups revealed significant differences ($p < .05$) between each age group (see Table 2). For the rotation subscale, there was a significant effect for subjects' age ($F[4, 183] = 18.39, p < .0001$). The post hoc comparison suggested that a jump in the frequency rotation was used between the 4-year-old and 5-year-old subjects (see Table 2).

In the analysis of variance for the subscale finger-to-palm translation, there was a significant age-group effect ($F[4, 179] = 14.9, p < .0001$). Post hoc comparisons revealed that 2-year-old subjects did significantly fewer finger-to-palm translations than did subjects in the older age groups (see Table 2). Twenty-five percent of the subjects between 2 and 2½ years old did not demonstrate any finger-to-palm translation with stabilization. Among subjects 2½ years to 3 years old, 5% did not demonstrate finger-to-palm translation. All older age groups

<table>
<thead>
<tr>
<th>Group (Size)</th>
<th>Manipulate (Subscore) [Range of Scores]</th>
<th>Rotation (Subscore) [Range of Scores]</th>
<th>Finger to Palm (Subscore) [Range of Scores]</th>
<th>Palm to Finger (Subscore) [Range of Scores]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to 3 years (n = 42)</td>
<td>12.7 (7.5)$^a$ [0-29]</td>
<td>1.1 (1.9) [0-9]</td>
<td>9.3 (4.7)$^a$ [0-13]</td>
<td>2.3 (2.4)$^a$ [0-9]</td>
</tr>
<tr>
<td>3 to 4 years (n = 43)</td>
<td>19.1 (5.8)$^a$ [0-34]</td>
<td>1.9 (2.7) [0-10]</td>
<td>12.3 (1.9) [0-13]</td>
<td>4.9 (2.7)$^a$ [0-13]</td>
</tr>
<tr>
<td>4 to 5 years (n = 41)</td>
<td>22.8 (5.3)$^a$ [0-36]</td>
<td>2.8 (3) [0-10]</td>
<td>12.9 (5) [0-13]</td>
<td>7.3 (3.7) [0-15]</td>
</tr>
<tr>
<td>5 to 6 years (n = 29)</td>
<td>26.0 (4.2)$^a$ [0-36]</td>
<td>4.9 (2.7) [0-10]</td>
<td>12.9 (6) [0-13]</td>
<td>8.3 (3.4)$^a$ [0-13]</td>
</tr>
<tr>
<td>6 to 7 years (n = 24)</td>
<td>30.5 (4.8)$^a$ [0-36]</td>
<td>5.4 (3.1) [0-10]</td>
<td>12.9 (4) [0-13]</td>
<td>11.3 (2.7) [0-13]</td>
</tr>
</tbody>
</table>

$^a$Post hoc contrasts between the age group and the next older group suggest significant differences ($p < .05$).
demonstrated consistent finger-to-palm translation with stabilization.

For the analysis of variance of the palm-to-finger translation subscale, there was a significant age-group effect (\(F[4, 177] = 37.61, p < .0001\)). The comparison between the 4- and 5-year-old group was the only adjacent age group that was not significantly different (see Table 2).

**Consistent Use of Rotation**

The correlation between frequency of rotation used with the pen and the pegs was .41 (\(p = .0001\)). To further explore the extent to which subjects used rotation as a manipulation strategy in the different activities, the percentage of subjects in each age group who never used rotation, used it inconsistently (score from 1 to 4), and always used it was examined (see Table 3). Among the 5-year-old and younger groups, the peg appeared to elicit rotation more often than the inverted pen. Even among the 6-year-old group, however, rotation was used consistently in each activity by fewer than half of the subjects.

**Relationship Between In-Hand Manipulation and Activities**

The final research question examined was the relationship between observations of in-hand manipulation abilities and activities where intrinsic hand function might occur. The magnitude of the correlations between the total manipulation score and the different measures of functional activities ranged from .47 to .65, and all correlations were significant \((p < .0001)\). In all the stepwise regression analyses, the subjects' ages were the strongest single predictor of performance of activities (see Table 4). Subscale scores contributed from 1% to 3% additional explained variance.

The score for the maturity of grasp of a pencil and crayon was also examined with stepwise regression analysis. The same procedure was used for the summed score for grasp on the spoons during the two scooping activities. In both regression models, age of the subjects continued to provide a large portion of the explained variance in the grasp of a tool (see Table 5).

**Discussion**

**Age-Related Differences**

This study supports Exner's (1990a) conclusion that in-hand manipulation abilities emerge during the preschool years. At the same time, the majority of the 6-year-old subjects did not receive maximum possible scores, suggesting that the in-hand manipulation ability continues to develop. The positive, moderate correlations between age and observed frequency of in-hand manipulation adds to the construct validity for the developmental nature of this fine motor skill. The earliest and most consistent form of in-hand manipulation was finger-to-palm translation. As with Exner's (1990a) work, more than half of the 2-year-old subjects demonstrated finger-to-palm translation.

The findings of the present study do not completely replicate Exner's (1990a) work. In the present study, fewer than half of the subjects in the 3-year-old group used rotation to reposition the 3/4-in. bead peg 180°, whereas Exner (1990a) reported that 50% of her subjects younger than 2 1/2 years used rotation with a 3/4-in. peg. In light of a

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Subjects Demonstrating No Rotation, Some Rotation, and Rotation Daring All Five Opportunities for Each Item</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rotation With Pen</td>
</tr>
<tr>
<td>Group</td>
<td>None (%)</td>
</tr>
<tr>
<td>2 to 3 years (n = 42)</td>
<td>95 7 0</td>
</tr>
<tr>
<td>3 to 4 years (n = 44)</td>
<td>82 11 7</td>
</tr>
<tr>
<td>4 to 5 years (n = 44)</td>
<td>55 40 5</td>
</tr>
<tr>
<td>5 to 6 years (n = 29)</td>
<td>38 48 14</td>
</tr>
<tr>
<td>6 to 7 years (n = 25)</td>
<td>16 44 40</td>
</tr>
</tbody>
</table>

*Some = scores ranged from 1 to 4.
Table 5
Results of Stepwise Regression Analysis of Age and the In-Hand Manipulation Subscores for Explained Variance of Subjects' Grasp of Tools

<table>
<thead>
<tr>
<th>Task</th>
<th>Partial Correlation</th>
<th>Model of Explained Variance</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasp of pencil during Developmental Test of Visual Motor Integration and crayon while coloring the triangle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.50</td>
<td>.50</td>
<td>183.28</td>
<td>.0001</td>
</tr>
<tr>
<td>Trans. palm-to⁴</td>
<td>.02</td>
<td>-.26</td>
<td>7.33</td>
<td>.007</td>
</tr>
<tr>
<td>Grasp of spoon while scooping beans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.23</td>
<td>.23</td>
<td>54.04</td>
<td>.0001</td>
</tr>
<tr>
<td>Rotate</td>
<td>.03</td>
<td>.26</td>
<td>6.24</td>
<td>.01</td>
</tr>
</tbody>
</table>

⁴Partial correlation is the percentage of explained variance uniquely contributed by each variable as it is added to the model.
⁵Trans. palm-to = palm-to-finger translation.

dynamical systems model, variations in procedures and materials suggest caution in drawing conclusions about similarities or differences. More research is needed to examine how the activity, the instructions, and the size of the objects may have contributed to differences in findings between Exner's (1990a) study and the present study.

The present study illustrates some important points about concepts related to fine motor development. In the analysis of variance, there were significant differences between each age group for the total manipulation score. The analyses of subscale scores suggest that the increasing use of in-hand manipulation does not follow the same incremental or linear trend for the different categories (see Table 2). First, a ceiling was reached at 3 years of age in finger-to-palm translation, and there were no developmental changes between 3 and 6 years of age. A significant increase in frequency of rotation was found between the 4-year-old group and the 5-year-old group, in contrast to the palm-to-finger translation subscale scores where the 4- and 5-year-old groups were the only adjacent ages that were not significantly different. If there was only one system underlying changes in fine motor abilities, such as maturation of the nervous system (motor cortex and the corticospinal spinal tract), matching patterns of differences between age groups might be anticipated for all categories of in-hand manipulation.

Findings of the study suggest the need to consider in-hand manipulation development in light of the dynamical systems model. For example, developmental changes of various subsystems (e.g., hand size, neurological basis for isolated finger movements, perceptual understanding of the spatial orientation of objects felt in the hand, and motor planning) at different times could each contribute to emerging palm-to-finger translation. Physical growth during early preschool years (between 2 and 3 years of age) may reduce the problem of hand size as a factor in translating ¾-in. objects, but the other factors would still contribute to immature performance. Among 4-year-old children, hand size and maturation of the nervous system may be adequate to support moderate performance so there would be a significant difference between 3- and 4-year-old groups. Four-year-old children may still lack perceptual understanding of spatial orientation of objects in the hand and motor planning to enable them to do palm-to-finger translation without sometimes dropping objects. The maturation of subsystems allowing for perception of spatial orientation of objects in the hand and motor planning may only occur after 5 years of age. This hypothetical application of a dynamical systems approach would account for emerging abilities that seem to plateau between 4 and 5 years of age even though the subjects in these two age groups were significantly different in rotation.

Stability of Rotation
The consistency with which a subject used rotation was the second issue examined (see Table 3). Even among 5- and 6-year-old subjects, rotation was used an average of only 5 of the 10 opportunities. Kamm et al. (1990) have suggested that a movement pattern is identified as most efficient for a specific activity and used repeatedly so a predictable pattern emerges. The present study suggests that preschool children may not be attracted to a single pattern of manipulation to turn objects and that variation should be expected.

For a consistent pattern of movement to emerge from a dynamical system, efficacy is an assumed criterion (Kamm et al., 1990). In the preschool child, the process of doing the activity could hold the child's attention so some manipulation patterns may not be perceived as inefficient and therefore may be used alternatively with rotation. A child may not be attracted to use a single pattern until the product of the activity becomes more important. Consistent selection of an in-hand manipulation pattern as part of doing an activity may not emerge until cognitive changes permit attention to process and product so the child is inclined to use the most efficient movement.

Dynamical systems approach also suggests that subtle changes in subsystems from moment to moment could result in the use of alternatives to rotation over repeated trials. A weight shift that changed posture, fatigue, and interest in the activity could each influence the manipulation strategy selected. Whether adults spontaneously and consistently use rotation has not been explored, so position, fatigue, and interest could continue to contribute to some variations over repeated trials regardless of age.

Whether variations are due to lack of readiness to evaluate manipulation patterns for efficiency or changes in subsystems, not using a consistent motor pattern may be an advantage for the developing child. Variation in
motor strategies provides diverse sensorimotor learning opportunities. For example, using both hands to collaboratively reposition an object (the most common alternative strategy to rotation) offers bilateral manipulation experiences. Thus, it may not be to the child’s advantage to be trained to use just one manipulation pattern.

In addition to examining the consistency of rotation over repeated trials with the same object, the present study considered whether rotation emerged at the same time with differently sized objects (i.e., the pen and peg). The modest correlation (r = .41) between the two items contributing to the rotation subscale score suggests that some subjects who were consistent in using rotation with a pen were less consistent using rotation with a peg. At the same time, other subjects were more consistent with the peg than with the pen. The study illustrates that generalized ability may not be assumed and supports the importance of considering a task-oriented approach (Mathiowetz & Haugen, 1994). In treatment situations, learning manipulation skills in the context of the activity where the movement pattern will be applied would be one way of compensating for reduced generalization.

In-Hand Manipulation and Performance of Activities

This study also examined the extent to which in-hand manipulation abilities related to performance in activities that required intrinsic hand movements. A significant association in typically developing children would strengthen an argument for practicing a component of movement as a means of enhancing dexterity in activities. Correlations between measures of in-hand manipulation skill and selected measures of speed, ability, and control in activities were moderate; however, the importance of considering the effects of age is demonstrated. In all of the regression analyses, once the effect of age was controlled, scores from the in-hand manipulation subscales contributed only 2% or 3% of the explained variance. This finding suggests that the subsystems that constrain more mature performance in the selected activities may not be the fine motor abilities reflected by in-hand manipulation skills.

The small association between measures of in-hand manipulation skill and performance of the three activities suggests a concern if intervention strategies target just one subsystem such as dexterity. Other research has found no relationship between gains in measures of the musculoskeletal system, range of motion or hand strength, and functional activities (Hill, 1994). It is hypothesized that mature manipulation skills could be necessary but not sufficient for skilled performance in the selected activities. If this were the case for children with developmental delays, treatment that targets in-hand manipulation may not directly affect occupational performance. In developing an intervention plan, it may be helpful to distinguish between motor development and motor learning. During general skill development, dexterity and motor control may be challenged with therapy that includes a variety of manipulation toys. Once the child starts to show a fine motor ability, intervention may need to focus on promoting motor learning with appropriate practice and feedback opportunities within the context of occupational performance to ensure that the skill is applied to the activity.

Limitations

Generalization of scores from this study is limited because the sample of children was homogeneous and does not reflect the ethnic or socioeconomic diversity that a random sample would obtain. This study was conducted on typically developing children, so application to children with developmental disabilities, who may follow alternative patterns of development, is another limitation. As Exner’s (1992) instrument is further developed, normative data with a more representative sample on a variety of in-hand manipulation items may be available for clinical use.

Validity of activities selected in this research protocol could be another limitation of the study. Parents’ and teachers’ expectations for occupational performance of preschool children guided choice of activities but were not confirmed through a panel of experts. Different activities that use intrinsic hand movements could lead to other results than those reported here. In addition, the extent to which selected activities relate to performance of tasks such as dressing or participating in art time in preschoolers has not been demonstrated.

Conclusion

The confirmation of age-related differences in performance of rotation and translation reflects a traditional organismic or milestone approach to in-hand manipulation. The uneven pattern of developmental changes in the different categories of in-hand manipulation and the inconsistent use of rotation among children who demonstrated the ability has suggested that a dynamical systems approach to motor development could be used to further understand the results. A dynamical systems approach calls attention to the fact that fine motor skills are a product of interdependent subsystems. The study also illustrated that knowing the status of in-hand manipulation skills did not substantially help predict performance of typically developing children in a variety of preschool activities.

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References


