Motor Sequencing Strategies in School-Aged Children

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The purpose of this study was to gain further insight into the normal development of praxis in children and to identify some of the learning strategies used by children during a motor-sequencing task. I analyzed the errors made by kindergarten and third-grade children during a motor-sequencing task and their reported memory strategies. I studied the following three groups of children: kindergarteners who could not learn the motor-sequencing task, kindergarteners who did learn the task, and third graders. The groups were significantly different with respect to age, their ability to perform a cognitive sequencing task, the number of perseverations made during the motor task, and the time required to perform a correctly recalled motor sequence. The kindergarteners tended to use kinesthetic coding for recall, and third graders more often used verbal rehearsal. The notion that motor sequencing develops along an orderly continuum with increasing age was supported. The results suggest that when teaching children motor-sequencing tasks, learning is enhanced by using verbal rehearsal of relevant movement labels.

Key Words: Child development, Motor skills, Physical therapy.

The characteristics of apraxia seen in brain-damaged adults have been analyzed extensively. Most of this research has occurred independently of data on the normal development of praxis in children. Only recently has a theoretical framework been proposed that attempts to integrate findings from studies of apraxia and of normal motor behavior. Understanding the normal development of praxis will assist in the rehabilitation of adults with apraxia and the habilitation of children identified as clumsy. In this study, I defined praxis as the learned ability to sequence nonstereotyped, manual movements.

LITERATURE REVIEW

Motor sequencing is a learned skill and, according to Piaget, is one of the stages in the development of praxis. Studies involving the normal development of praxis in children have been varied with respect to age, the child's ability to perform a cognitive sequencing task, the number of perseverations made during the motor task, and the time required to perform a correctly recalled motor sequence. The kindergarteners tended to use kinesthetic coding for recall, and third graders more often used verbal rehearsal. The notion that motor sequencing develops along an orderly continuum with increasing age was supported. The results suggest that when teaching children motor-sequencing tasks, learning is enhanced by using verbal rehearsal of relevant movement labels.

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Models for motor memory include a hierarchy of codes that aid memory. Laabs defined two motor memory codes. The lower level code relies on kinesthetic input and is subject to spontaneous forgetting. The higher level code, a central memory mode, is enhanced with verbal rehearsal. Developmentally, the appearance of labeling as a mnemonic tool is an important step in the acquisition of motor memory because the use of verbal labels allows position cues to be analyzed cognitively rather than kinesthetically. Labeling implies the use of a specific word or phrase to represent a movement, but it does not necessarily include the repetition or rehearsal of that word or phrase. The spontaneous use of verbal rehearsal is the next stage in memory development. About 60% of 7-year-old children use spontaneous rehearsal. Rehearsal of verbal labels maintains items in short-term memory. Waugh and Norman have proposed that rehearsal of verbal labels permits the transfer of information to long-term memory.

Children who do not display the normal stages of praxis development have also been studied. Gubbay et al identified the clumsy child syndrome and concluded that clumsiness in children resulted from a failure of the development of normal praxis. They suggested that the term developmental apraxia be used.

The majority of research, however, related to the lack of praxis (ie, apraxia) was done with brain-damaged adults. Roy has summarized a historical overview of apraxia research and theory. He also studied adult hemiplegic patients as they performed a four-step manual sequencing task and developed an error analysis system that permitted the delineation and quantification of performance levels.

Similar quantification of errors made during motor sequencing has not been studied in children. An objective measurement of errors provides an important link in comparing the motor-sequencing performance of developmentally normal children with both the motor-sequencing performance of children displaying developmental apraxia and with apraxic adults. I, therefore, adapted Roy’s motor-sequencing task and error analysis for use with children and evaluated the protocol during a pilot study before beginning this study. The purpose of this study was to gain further insight into the normal development of praxis in children and to identify some of the learning strategies used by children during a motor-sequencing task. I hypothesized that younger children would make more and different types of errors while attempting to learn the motor-sequencing task than the older children. I also hypothesized that the older children would be able to identify a specific memory strategy and would, therefore, learn the task more quickly.

### TABLE 1
Summary of Age and Sex Data for Subject Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (X ± s)</th>
<th>Boys (n)</th>
<th>Girls (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonlearning kindergarteners (n = 21)*</td>
<td>5 yr 6.7 mo ±3.8 mo</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>Learning kindergarteners (n = 30)</td>
<td>5 yr 9.1 mo ±4.2 mo</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Third graders (n = 30)</td>
<td>8 yr 8.6 mo ±4.4 mo</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

* Children who did not meet the learning criterion for the motor-sequencing task.

### Subjects
I selected my 81 subjects from kindergarten and third-grade classrooms in a generally white, middle-class, university community. When I received written permission from the parents, I assigned the children to groups according to grade, sex, and the following selection procedure. For the Third-Grade Group, I accepted the first 15 boys and 15 girls whose parents gave permission provided the children were available for the study and were not identified by parents or teachers for having motor problems, receiving speech therapy, or attending special education classes. For the Kindergarten Group, I identified 15 girls and 15 boys who could successfully meet the learning criterion for the motor-sequencing task. I classified these 15 girls and 15 boys as the Learning Kindergarten Group. I had to test 51 kindergarteners to select the group who met the learning criterion. The other 21 kindergarteners, from the 51 tested, who could not meet the learning criterion were classified as the Nonlearning Kindergarten Group. Table 1 contains descriptive data for each group.

### Design
My study design required testing of kindergarteners and third-grade children on two tasks: a developmental measurement pretest and a motor sequence task. The pretest consisted of collecting baseline data on cognitive memory with colored squares, apraxia appraisal with a finger-tapping trial, and a movement timing without performing any sequencing tasks. The motor-sequencing task began with a practice trial with action-picture cards placed on the test board. The trials using action-picture cards were classified as practice trials. The trials without the action-picture cards were classified as memory trials. I established a learning criterion (a higher level than that set for the practice trial) as completion of five, consecutive error-free memory trials for the motor-sequencing task. I also conducted a posttest to determine subject retention of the motor-sequencing skills.

### Equipment and Testing Environment
Both the apparatus for testing the motor-sequencing task and the testing procedure were very similar to those used by Roy. Six knobs were mounted on a board (Figure). The bottom knob started the timer, and the top knob switched off the timer. The children performed the motions pull, point, turn, and slide with the four knobs located vertically between the top and bottom knobs. Action-picture cards depicted these motions during the practice trials of the study (Figure). The testing room had minimal auditory and visual distraction. I tested the children individually and completed all the testing in one session.

### Testing Procedures
Pretesting. Baseline data included a cognitive memory score, finger-tapping score, and movement-time score. The cognitive memory score reflected the child’s ability to remember a sequence of colored squares. The children viewed a random sequence of colored squares for one second for each square. I then removed the colors and asked the children to create the same sequence from a group of colors placed in
Groups. The Rehearsal Group contained children who re­
tested memory strategies into Rehearsal and Nonrehearsal
scores equal to the number of colors in the previous correctly
presented a sequence with one additional color. Two consec­
tive failures stopped the pretest, and I recorded a memory
score was an average of the number of taps in each of the three
trials.

The movement-time score reflected the time needed by the
children to move their index finger from the starting switch
to the stopping switch and to touch each of the four knobs
on the testing board along the way. The final movement-time
score was an average of the three timings.

Motor-sequencing task. After the children were able to
perform successfully the individual actions illustrated on the
action-picture cards, I placed the cards on the motor-sequenc­
ning board in the same random order used by Roy (ie, pull,
turn, point, and slide). The trials using the action-picture
cards were identified as practice trials. My instructions em­
phasized the need to make the correct action the first time
without mistakes. If the sequence was performed correctly, I
then removed the action-picture cards and asked the children
to perform the sequence again by memory. The trials without
the action-picture cards were classified as memory trials.

I defined learning as completion of five consecutive error­
free memory trials. During the pilot study, I had determined
that the 24 trials used by Roy were an adequate number to
permit learning to occur in children, but not too numerous
to cause boredom or fatigue. If the children made an error
during a memory trial, I instructed them to practice again
with the action-picture cards. A successful completion of the
sequence with the cards (ie, a practice trial) was necessary
before the children could again attempt a memory trial. After
learning the sequence, or after a total of 24 trials, I asked
the children to identify a learning strategy. I recorded and later
classified the memory strategies into Rehearsal and Nonre­
hearsal Groups in the same manner as previously described
for the cognitive memory pretest.

For measurements of the motor-sequencing task, response
time equaled the time from the start to the finish of each
motor sequence. I recorded each child’s action responses
and then analyzed the responses for errors. Because the number
of trials performed varied among subjects, analyses included
an averaging of specific measurements across trials. I identi­
fied trials as either correct (ie, no errors) or incorrect and as
either practice (ie, using action-picture cards) or memory. The
total number of trials needed to complete successfully five
consecutive memory trials without error reflected learning
efficiency and met study learning criterion. Performance was
analyzed for accuracy and the type of error made for each
incorrect memory trial. I defined accuracy both as the
number of correct memory trials for total number of memory trials
and as the number of errors made for each incorrect memory
trial.

I defined four possible error categories. A sequencing error
of position occurred when an action was performed at the
wrong knob. Sequencing errors of order occurred when an
action was performed out of the prescribed order. When an
action was repeated at two or more successive positions, a
perseveration error was recorded. Omission errors occurred
when no action was performed at a knob.

Additional analyses were performed for sequencing errors
of position and order. Position or order errors could be either
simple or complex. I defined a combination of two position
errors and one order error as a complex sequencing error. I
also tabulated substitutions made during sequencing into
related and unrelated groups according to their kinesthetic
similarity with the correct action. Push, pull, and turn were
related with respect to hand postures and muscle group used.
Pointing was kinesthetically different and, therefore, rep­
resented an unrelated substitution.

Posttest. A posttest verified that after finishing the motor-
sequencing task, all children, even if they could not recall the
correct sequence, could still perform the individual motor
actions illustrated on the picture cards.

Data Analysis

The design of the study involved data collection from three
groups of children: kindergarteners who could not learn the
motor-sequencing task, kindergarteners who did learn the
task, and third graders, all of whom learned the motor-
task consisted of a one-factor analysis of variance (ANOVA) sometimes small. The statistical analyses for differences be-

with the two levels differing depending on the specific varia-

TABLE 3
Tabulation of Accuracy Measurements for the Motor-
Sequencing Task

<table>
<thead>
<tr>
<th>Measurement and Group</th>
<th>X ± s</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct memory trials (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonlearning kindergarteners</td>
<td>0.62 ± 0.14</td>
<td>11.39</td>
<td>.001</td>
</tr>
<tr>
<td>Learning kindergarteners</td>
<td>0.75 ± 0.15</td>
<td>df = 1.58</td>
<td>.01</td>
</tr>
<tr>
<td>Third graders</td>
<td>2.36 ± 1.38</td>
<td>74.50</td>
<td>.0001</td>
</tr>
<tr>
<td>Errors for each incorrect trial (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonlearning kindergarteners</td>
<td>3.67 ± 0.82</td>
<td>0.24</td>
<td>NS</td>
</tr>
<tr>
<td>Learning kindergarteners</td>
<td>3.56 ± 0.93</td>
<td>4.01</td>
<td></td>
</tr>
<tr>
<td>Third graders</td>
<td>3.22 ± 0.80</td>
<td>df = 1.53</td>
<td>.05</td>
</tr>
</tbody>
</table>

* Represents the maximum number of correctly sequenced color cards.

b df = 1.49.
c df = 1.58.

Age Differences

The nonlearning kindergarteners (X = 5 years, 6.7 months) were significantly younger than the learning kindergarteners (X = 5 years, 9.1 months) (F = 4.44; df = 1.49; p = .04).

Motor-Sequencing Task

Response time. When I compared by grade the response times for each correct memory trial, third graders were signifi-
cantly faster than learning kindergarteners (F = 55.5; df = 1.57; p = .0001) and learning kindergarteners were signifi-
cantly faster than nonlearning kindergarteners (F = 4.71; df = 1.41; p = .04), nonlearning kindergarteners (X = 12.61 sec), learning kindergarteners (X = 9.64 sec), third graders (X = 5.66 sec). The board movement time pretest demonstrated, however, that third graders' movement times were inherently faster than learning kindergarteners. The unpartialed corre-
lation for these grades and time was r = -.70. An unpartialed or simple correlation measures the strength of association between two variables. In this case, the unpartialed correlation was between grade and response time. This simple correlation, however, ignored the effect of the board movement time variable, which, by definition, strongly correlated with re-

response time. A partial correlation defines the strength of association between two variables after adjusting for the other variable or variables. A partial correlation is needed, therefore, to compare the strength of relationship between grade and response time after accounting for the effects of board move-

ment time. A partial correlation for response time by grade, taking into consideration the differences in board movement time, revealed that significant response time differences be-
tween the Nonlearning Kindergarten and Learning Kindergarten Groups and the Learning Kindergarten and Third-

grade Groups were performed.

RESULTS

Pretests

Cognitive memory score. I found by using ANOVA that significant differences between subject groups existed at all levels (Tab. 2). The nonlearning kindergarteners correctly recalled fewer colors than the learning kindergarteners (p = .009). The learning kindergarteners scored lower than the third graders (p = .0001).

Finger tapping. Finger-tapping scores did not differentiate the learning and nonlearning kindergarteners. The third graders' average tapping score, however, was significantly larger (p = .0001) than the learning kindergarteners' score (Tab. 2).

Movement time. No significant differences in movement time existed between the two kindergarten groups. As I hy-

pothesized, the third graders' time was significantly faster (p = .0001) than the learning kindergarteners' time (Tab. 2).

TABLE 2
Tabulation of Pretest Data for the Three Subject Groups

<table>
<thead>
<tr>
<th>Pretest and Group</th>
<th>X ± s</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive memory (score)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonlearning kindergarteners</td>
<td>2.10 ± 0.94</td>
<td>&gt; 7.31</td>
<td>.009</td>
</tr>
<tr>
<td>Learning kindergarteners</td>
<td>3.00 ± 1.31</td>
<td>&gt; 18.90</td>
<td>.0001</td>
</tr>
<tr>
<td>Third graders</td>
<td>4.27 ± 0.91</td>
<td>&gt; 0.01</td>
<td>NS</td>
</tr>
<tr>
<td>Finger tapping (taps)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonlearning kindergarteners</td>
<td>36.0 ± 5.1</td>
<td>&gt; 0.01</td>
<td>NS</td>
</tr>
<tr>
<td>Learning kindergarteners</td>
<td>35.9 ± 6.2</td>
<td>&gt; 35.68</td>
<td>.0001</td>
</tr>
<tr>
<td>Third graders</td>
<td>45.5 ± 6.3</td>
<td>&gt; 74.50</td>
<td>.0001</td>
</tr>
<tr>
<td>Movement time (sec)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonlearning kindergarteners</td>
<td>2.53 ± 0.38</td>
<td>&gt; 2.50</td>
<td>NS</td>
</tr>
<tr>
<td>Learning kindergarteners</td>
<td>2.36 ± 1.38</td>
<td>&gt; 74.50</td>
<td>.0001</td>
</tr>
<tr>
<td>Third graders</td>
<td>1.69 ± 0.20</td>
<td>&gt; 74.50</td>
<td>.0001</td>
</tr>
</tbody>
</table>

* Represents the maximum number of correctly sequenced color cards.

b df = 1.49.
c df = 1.58.

Sequencing task. A preliminary analysis using a Pearson cor-

relation was performed on all data before specific group analysis. Data analysis for the pretest and motor-sequencing task consisted of a one-factor analysis of variance (ANOVA) with the two levels differing depending on the specific vari-

ables. The chi-square test of independence was also used be-

cause of its robustness even though expected frequencies were sometimes small. The statistical analyses for differences be-

 tween the Nonlearning Kindergarten and Learning Kindergarten Groups and the Learning Kindergarten and Third-

grade Groups were performed.
accuracy, the third graders were significantly more accurate (Tab. 3). Using the number of errors made for each incorrect trial as an additional measure of accuracy, the third graders were again significantly more accurate (Tab. 3). Accuracy differences between the two kindergarten groups were not significant.

**Error analysis.** The total number of each error type for each incorrect motor trial is recorded in Table 4. I used an ANOVA to analyze these results in two ways. First, I compared each error type separately between grades. The only significant difference was the number of perseverations for each incorrect memory trial—nonlearning kindergarteners and learning kindergarteners ($F = 6.35; df = 1.48; p = .02$), learning kindergarteners and third graders ($F = 5.62; df = 1.53; p = .02$). The second method of analysis of the data shown in Table 4 involved comparing the proportion of the four error types relative to the total error. The impact of error type on total errors did not distinguish nonlearning kindergarteners from learning kindergarteners ($F = 0.60; df = 3.144; p = NS$) or learning kindergarteners from third graders ($F = 0.68; df = 3.159; p = NS$).

I then analyzed position and order errors (Tab. 5). Third graders averaged significantly more simple error trials than learning kindergarteners ($F = 4.51; df = 1.52; p = .04$). Learning kindergarteners made substitution errors using a kinesthetically similar action significantly more often than third graders ($F = 5.44; df = 1.53; p = .02$).

**Memory strategy.** No significant differences existed between the two kindergarten groups’ use of rehearsal as a memory strategy (Tab. 6). When comparing learning kindergarteners and third graders, however, significant differences in the use of rehearsal and nonrehearsal strategies existed for both the cognitive and motor tasks (cognitive task: $χ^2 = 27.15, df = 1, p = .001$; motor task: $χ^2 = 6.67, df = 1, p = .01$). As Table 6 demonstrates, 14 third graders switched from a rehearsal strategy on the cognitive task to a nonrehearsal strategy on the motor task (one child switched from nonrehearsal to rehearsal). McNemar’s test for dependent proportions was used to analyze this distribution. The strategy switches among third graders were found to be significant ($z = 3.14, p < .01$).

**DISCUSSION**

**Developmental Trends**

This study supports the notion that praxic ability changes and improves with increasing age. The third graders learned faster and demonstrated a more mature response for every factor that discriminated between learning kindergarteners and third graders. Also, learning kindergarteners demonstrated a higher level of proficiency in most areas tested than the younger nonlearning kindergarteners.

Response times decreased with increasing age even when inherent differences for movement time were accounted for. Response time was a difficult factor to analyze because the time measured in this study was for the interval from the start to the end of a correct motor sequence. The time between trials varied among subjects and was not included in the response-time measurement. Response time, therefore, reflected the time needed to perform the motor actions, the time needed to initiate movement and to make transitions between actions in the sequence, and strategy-planning time for verbal rehearsal and retrieval of coded information. I hypothesized that if the third graders used intertrial time for planning and rehearsing, their response times would be less. In addition, Belmont and Butterfield have shown that with increasing age, the speed of retrieval of rehearsal material increases. The remaining response time for third graders would, therefore, reflect the time needed to initiate postural changes between motor tasks and time to perform the actual motor task. Because kindergarteners took more time to respond, possibly they did more of their planning during the sequencing task itself. Chi proposed that the developmental differences in processing, reflected in reaction time, are due to the use of inefficient memory strategies.

The increased tendency of younger children to perseverate partially supports the assumption that younger children take longer to make postural changes. Roy identified perseverations as a motor rather than conceptual phenomenon and as
a characteristic of pathological error. In this study, perseverations occurred as a part of the normal sequence of praxis development. In normal children, perseverations seem to reflect an immature CNS rather than a damaged one. Even though the occurrence of perseverations decreased with increasing age, the overall profile of errors appeared to remain constant with increasing age. When the four error types were proportioned with respect to total error, the resulting profiles were not significantly different. For all three groups, position errors averaged about 58.6% of total errors, order errors about 37.7%, perseverations about 3.3%, and omission errors about 0.4%. Hypothetically, a child with a damaged CNS might present a different error profile. If perseverations represented a significantly higher percentage of total error than is found in normal development, then perseverations could be identified as a pathological error type in that child.

When learning kindergarteners substituted an incorrect action, their substitutions were based on kinesthetically similar actions. These substitutions imply that they were using kinesthetic input as a memory code. As Laabs has shown, kinesthetic coding is subject to forgetting and does not provide a firm foundation for recall. A more mature strategy would involve the use of verbal labels for the actions so that verbal rehearsal can be used for coding. Both the cognitive and motor-sequencing tasks appeared to be aided by the use of a mnemonic strategy. Mnemonic strategy development must be an important factor in successful praxis development. The strategy switches, however, reported by the third graders in this study imply that the spontaneous use of rehearsal for motor-sequencing tasks does not develop at the same rate as the use of rehearsed verbal labels for cognitive-sequencing tasks.

Model for Motor-Sequencing Behavior

Roy pointed out that any model that is relevant for apraxia must account for both conceptual and production aspects. He considered knowledge of the serial order of actions in a sequence to be part of the conceptual base and identified timing of movements, accuracy of performance, and perseverations as production components. The differences found between the two kindergarten groups and between the learning kindergarteners and third graders support a model of praxis development that includes changes in both the conceptual and production areas. Because the younger children did not possess the ability to rehearse verbal labels, they had a more difficult time remembering the serial order of the motor tasks. Production problems in the younger children caused an increase in the number of perseverations while performing the motor-sequencing task and a decrease in accuracy.

Increased response times for the younger children may reflect both immature planning strategies and difficulty initiating a transition between movements. Additional research that more carefully analyzes response time is needed to sort out the conceptual and production aspects.

CONCLUSIONS

The factors that characterize the normal sequence of praxis development in children have important implications for physical therapists attempting to teach a school-aged child a motor sequence. Motor-sequencing tasks must be placed on a cognitive level for initial learning with recall to occur efficiently and effectively. Children below first grade rely primarily on kinesthetic coding of movement and do not spontaneously rehearse relevant verbal labels. Therefore, when teaching a specific motor task, a physical therapist should first identify the relevant movement labels and then teach the young school-aged (under 7 to 8 years) child to rehearse verbally the labels in sequence. Physical therapists should provide adequate time both before initiating a new motor sequence and between subtask execution. Time must be provided to rehearse, to retrieve rehearsed items, and to initiate a shift in postures.

Future research with developmentally apraxic children is needed to reveal if they make the same type of errors during a motor-sequencing task as do normally developing children. If the error analysis is completely different, then possibly developmental apraxia should not be considered a simple disruption in the normal development of praxis. Similar disruptions, however, in planning strategies and motor execution would suggest a therapy model consistent with that proposed by Roy and with the findings of this study.

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REFERENCES