The Effects of Sensorimotor-Based Intervention Versus Therapeutic Practice on Improving Handwriting Performance in 6- to 11-Year-Old Children

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OBJECTIVE. The aim of this study was to investigate the effects of two interventions (sensorimotor and therapeutic practice) on handwriting and selected sensorimotor components in elementary-age children.

METHOD. Thirty-eight children 6 to 11 years of age with handwriting dysfunction but no identified educational need were randomly assigned to one of the two intervention groups or a control group. Intervention groups met four times per week over 5 weeks. Handwriting was measured pre- and postintervention using the Test of Handwriting Skills. Visual perception (motor-reduced), visual-motor integration, proprioception, and in-hand manipulation were also measured.

RESULTS. Children receiving therapeutic practice moderately improved handwriting whereas children receiving sensorimotor intervention declined in handwriting performance. The control group did not change significantly. Sensorimotor impairment was noted at pretest in three or four components and selected sensorimotor component function improved with intervention.

CONCLUSION. Therapeutic practice was more effective than sensorimotor-based intervention at improving handwriting performance. Children who received sensorimotor intervention improved in some sensorimotor components but also experienced a clinically meaningful decline in handwriting performance.


Introduction

Occupational therapists frequently receive referrals to treat impaired handwriting performance in elementary school-age children (Benbow, 1995; Reisman, 1991). Although keyboarding may serve as a compensatory approach for illegible handwriting in some children (Preminger, Weiss, & Weintraub, 2004), handwriting is necessary for assignments, homework, and many tests including standardized tests (high school achievement and college preparatory) for the majority of children. Elementary school-age children have been found to engage in paper and pencil tasks more frequently than manipulative tasks during a significant portion of the school day (McHale & Cermak, 1992). Thus, legible handwriting continues to be an important skill for children to develop in elementary school and difficulty with this area can affect any child’s proficiency at schoolwork.

Most occupational therapy interventions for handwriting dysfunction are based on the assumption that the relationship between sensorimotor impairment and dysfunctional handwriting is causal: that is, sensorimotor impairment results in handwriting dysfunction. It is further assumed that remediation of these underlying impaired sensorimotor components will result in improved handwriting performance (Tseng & Cermak, 1993). Feder, Majnemer, and Synnes (2000) found that 90% of the Canadian occupational therapists surveyed used sensorimotor approaches to remediate sensorimotor impairment for children with handwriting dysfunction. Similarly, Woodward and Swinth (2002) found that 92% of American school-based therapists surveyed used a multisensory approach to treat sensorimotor impairments in children with dysfunctional handwriting. Although some therapists may exclusively use a sensorimotor approach with little or no handwriting practice, others may select a skill-based approach using practice and specific motor-
learning strategies. Commercially available handwriting intervention programs combine some form of sensorimotor intervention with letter formation practice (Amundson, 1998; Benbow, 1990; Laufer, 1993; Olsen, 1998). In fact, using an eclectic approach is noted as common practice in surveys of pediatric therapists (Feder et al., 2000).

The assumption that handwriting dysfunction is caused by sensorimotor impairment is evident in assessment practices as well. Feder et al. (2000) found that therapists regularly (> 90%) assessed gross or fine motor skills, perceptual skills, quality of movement, and motor planning in children with handwriting and/or fine motor difficulties. Handwriting performance was assessed much less frequently (< 15%).

The sensorimotor components that have been studied and believed to be related to handwriting include: visual perception, kinesthesia, in-hand manipulation, and visual-motor integration. Biomechanical factors including body posture and pencil grip have also been considered. Evidence for this relationship comes primarily from correlational studies. For example, despite theoretical beliefs that visual perception is necessary for letter recognition (Fisher, Murray, & Bundy, 1991; Yost & Lesiak, 1980) and is considered an essential component of handwriting (Benbow, Hanft, & Marsh, 1992), empirical evidence relating visual perception and handwriting is sparse. In a review of the literature, Tseng and Cermak (1993) summarized the findings of four correlational studies demonstrating weak or no relationship between visual perception and handwriting. In these studies, visual perception was measured using a motoric response. Measured in this way, impaired motor skills may have had a confounding effect on the relationship between visual perception and handwriting. The relationship between visual perception, measured without requiring a motor response (motor-free) and handwriting has not yet been satisfactorily investigated.

Similarly, knowing the position of one’s limbs and body, with vision occluded, is believed to exert a significant influence on development of a skilled movement like handwriting (Benbow, 1995; Cunningham-Amundson, 1992; Laszlo & Bairstow, 1983, 1984; Maeland, 1992). However, systematic measurement and treatment of kinesthesia rarely occurs in practice (Cope & Denton, 2004). Active proprioception instruments are thought to yield more accurate measures of proprioception that contribute to movement than passive instruments (Rösblad, 1995). The effectiveness of kinesthesia training on improving handwriting has been mixed (Harris & Livesey, 1992; Sudsawad, Trombly, Henderson, & Tickle-Degnen, 2002). In sum, knowing the position of one’s body in space intuitively appears related to handwriting performance, but this connection has not yet been empirically established.

Also, precise and rapid manipulation of a pencil has been proposed as essential for handwriting (Benbow, 1995; Exner, 1995). Exner identifies five types of in-hand manipulation: simple rotation, complex rotation, finger to palm translation, palm to finger translation, and shift. These manipulative skills are used to turn the pencil over to use the eraser and accurately manipulate the pencil through the fingers. However, exactly how in-hand manipulation affects handwriting has not yet been clearly demonstrated. Cornhill and Case-Smith (1996) found that both rotation and translation were significantly different between typically developing first graders with good and poor handwriting. On the other hand, Humphry, Jewell, and Rosenberger (1995) found very little relationship between in-hand manipulation and performance of several functional activities, including coloring, in typically developing children 2 to 7 years of age. Humphry and colleagues suggested that in-hand manipulation may be necessary but not sufficient for performance on fine-motor activities including handwriting.

Visual-motor integration, defined as the ability to look at a form and copy it accurately, is the only sensorimotor component that is moderately to strongly related to handwriting (Cornhill & Case-Smith, 1996; Daly, Kelley, & Krauss, 2003; Hagborg & Aiello-Coutlier, 1994; Maeland, 1992; Tseng & Murray, 1994; Weil & Cunningham-Amundson, 1994; Weintraub & Graham, 2000). In these studies, visual-motor integration was measured with the Developmental Test of Visual-Motor Integration (Beery, 1989). These correlational findings appear particularly robust since a relationship was demonstrated across different populations with different handwriting measures.

Relatively few investigations have been conducted to experimentally test the effectiveness of sensorimotor-based or other forms of handwriting interventions on handwriting performance in children. Peterson and Nelson (2003) combined sensorimotor, biomechanical, and teaching-learning interventions in a randomized control trial of 62 socioeconomically disadvantaged first-grade children without identified educational needs and who were not receiving occupational therapy services. The intervention group’s handwriting improved significantly more than those of the control group on the Minnesota Handwriting Test (Reisman, 1993). This study makes a significant contribution to the literature by demonstrating that handwriting can be improved with only 10 hours of occupational therapy intervention. However, it is not possible to determine the effectiveness of individual interventions because the interventions were tailored for each student. In addition, because the amount of therapy time was not controlled between the intervention and control groups, the impact of experimenter effects is unknown.
Another recent study examined handwriting in older children with more severe educational needs who were receiving occupational therapy services. Case-Smith (2002) studied 29 children, 7–10 years of age who had poor handwriting on the Evaluation Tool of Children's Handwriting (ETCH) (Amundson, 1995). Nine hours (on average) of occupational therapy intervention, spread over 7 months, were tailored for each student by the treating therapist and involved multiple interventions. These children were compared with typically developing children with poor handwriting but with no identified educational needs. The results showed that students receiving occupational therapy services made gains in handwriting legibility. This study is an attempt to quantify the effects of ongoing clinical practice. However, the lack of random assignment, equivalent control group, and equivalent intervention time undermines confidence in these results. As with the Peterson and Nelson (2003) study, the interventions used were eclectic; the impact of individual interventions cannot be determined.

Taking a somewhat different tack, Sudsawad et al. (2002) compared the effects of kinesthetic training with practice on handwriting in 30 first-grade children with no identified educational need. These children were teacher-referred as having poor handwriting and they all showed impaired kinesthesia as measured by the Kinesthetic Sensitivity Test (Bairstow & Laszlo, 1981). Handwriting was measured using the ETCH (Amundson, 1995). Children were randomly assigned to either of two interventions (kinesthetic activities or copying) or a control group. Kinesthesia improved in all groups with no difference between the groups. However, the improvement in kinesthesia did not result in handwriting improvement on the ETCH. This study was well-controlled; however, the short intervention time (3 hours) may have limited the effectiveness of both interventions. The practice group practicing copied handwriting samples with feedback but no attempt was made to incorporate motor-learning principles in this intervention. The expected link between kinesthesia and handwriting, previously found by Harris and Livesey (1992) was not supported in this study.

In an attempt to determine the effectiveness of motor-learning strategies for handwriting intervention, Ste-Marie, Clark, Findlay, and Latimer (2004) conducted a series of experiments with typically developing first-grade children to determine the effects of two forms of practice (blocked or random) on handwriting. In general, children who experienced random practice outperformed children who experienced blocked practice on production of most letters. These findings offer preliminary support that interventions based on motor-learning principles have a beneficial effect in improving handwriting.

Two older studies investigating the impact of sensorimotor interventions provide some preliminary evidence that sensorimotor approaches were effective in increasing both sensorimotor function and handwriting (Lockhart & Law, 1994; Oliver, 1990).

The intervention studies reviewed above varied greatly in the type of interventions used, population studied, and outcomes measured. Interventions used, sensorimotor-based, practice-based (motor-learning), or some combination of the two, represent different approaches theoretically and practically. Occupational therapy practitioners are more likely to use sensorimotor-based interventions or an eclectic approach according to previous experimental and survey research. This tendency to combine treatment approaches in experimental studies makes it difficult to draw clear conclusions about the effectiveness of any particular intervention on a specific outcome. Systematic comparisons of the effectiveness of specifically designed occupational therapy handwriting interventions are needed to test the relative effectiveness of these approaches. Moreover, more research is needed to test the assumption that remediation of sensorimotor components leads to improved handwriting performance.

Therefore, the purpose of this study was to investigate the effectiveness of two different handwriting intervention approaches on both handwriting and sensorimotor components. The following research questions guided this study:

-Did children's handwriting performance change due to the type of intervention received?
-Did children's sensorimotor component function change due to the type of intervention received?

**Method**

**Design**

This study used a three-group, pre- and posttest experimental design with random assignment to the sensorimotor (SM) \(n = 14\), therapeutic practice (TP) \(n = 15\), or control \(n = 9\) group. The raters were blinded to the children's group assignment and the children were unaware of the study's research questions.

**Participants**

To identify a sample of children with handwriting difficulty but no identified exceptional educational need, Gardner's Test of Handwriting Skills (THS) (1998) was administered to 200 typically developing children, 6 through 11 years of age. Approximately 25% of these children scored at least 1.5 standard deviations below the norm for their age. Children were recruited from six private schools in two cities in the Midwest. Ultimately, 38 children, 6.0 to 11.2 years of age
(M = 9.0, SD = 1.1), participated in this study. No attempt was made to balance the design by gender; 12 girls and 26 boys were included. One child broke her arm and did not participate in posttesting (Table 1). Inclusion criteria for the study were: (1) between 6.0 and 12.0 years of age; (2) no known physical problems that affected their handwriting; (3) normal or corrected vision; (4) no identified exceptional educational need; and (5) poor handwriting (1.5 SD or more below the mean for their age group on THS).

**Outcome Measures**

*Test of Handwriting Skills (THS).* The THS (Gardner, 1998) measures handwriting skills in children 5 to 11 years of age. Both manuscript and cursive versions are available and children were given the version that matched the predominant method of writing expected of them in school. The THS includes 10 subtests that use memorized, dictated, or copied stimuli to elicit written numbers, letters, or words. Each individual letter is scored by comparison with an exemplar. Individual letter scores are summed to obtain each subtest score. For this study, several subtests were combined and mean scores calculated for three constructed handwriting scales: memory (subtests 1–2), dictated (subtests 6–9), and copied (subtests 3–4 and 10).

The THS was normed on 345 children in the United States. Standard scores (M = 100, SD = 15) are available for each 3-month age increment. Internal reliability of the THS ranged from .29 to .87 (Gardner, 1998); other forms of reliability have not been tested. The subtest scores were moderately related to each other, suggesting that there is construct validity of the THS. Concurrent validity has also been studied (Gardner).

**Table 1. Participant Characteristics (N = 38)**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n</th>
<th>%</th>
</tr>
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<tbody>
<tr>
<td><strong>Age</strong> (M = 107.6 months, SD = 12.9 months)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 years old (72–83 months)</td>
<td>1</td>
<td>2.6</td>
</tr>
<tr>
<td>7 years old (84–95 months)</td>
<td>5</td>
<td>13.2</td>
</tr>
<tr>
<td>8 years old (96–107 months)</td>
<td>14</td>
<td>36.8</td>
</tr>
<tr>
<td>9 years old (108–119 months)</td>
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<td>29.0</td>
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<td>10 years old (120–131 months)</td>
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<td>11 years old (123–134 months)</td>
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<td>5.3</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>32</td>
</tr>
<tr>
<td>Boys</td>
<td>26</td>
<td>68</td>
</tr>
<tr>
<td><strong>Grade Level</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>1</td>
<td>2.6</td>
</tr>
<tr>
<td>Second</td>
<td>16</td>
<td>42.1</td>
</tr>
<tr>
<td>Third</td>
<td>14</td>
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<td>Fourth</td>
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<td><strong>Handwriting Format</strong></td>
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<td></td>
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<tr>
<td>Manuscript</td>
<td>32</td>
<td>84.0</td>
</tr>
<tr>
<td>Cursive</td>
<td>6</td>
<td>16.0</td>
</tr>
<tr>
<td><strong>Handedness</strong></td>
<td></td>
<td></td>
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<tr>
<td>Right</td>
<td>34</td>
<td>89.5</td>
</tr>
<tr>
<td>Left</td>
<td>4</td>
<td>10.5</td>
</tr>
</tbody>
</table>

*Developmental Test of Visual Perception (DTVP-2).* The DTVP-2 (Hammill, Pearson, & Voress, 1993) measures visual perception in children 4 to 10 years of age. It consists of a battery of eight subtests that use both motor-reduced and motor-enhanced formats. The DTVP-2 was normed on a sample of 1,972 children and standard scores are available (M = 10, SD = 3). Reliability for observer, time, and content of the subtests is reported to range between .89 and .94. The DTVP-2 is highly correlated with other measures of visual perception (.78–.87) providing strong evidence for criterion validity. Construct validity has also been demonstrated.

*Test of Manual Pointing (TMP).* The TMP (von Hofsten & Röblad, 1988) measures proprioception in children 4 to 12 years of age. The testing apparatus and protocol were based on von Hofsten and Röblad’s published specifications. Reliability and validity of the TMP have not been established, however it has been used to measure proprioception in children with motor disorders (Röblad & von Hofsten, 1992) and normative data on children in this age group are available (S. Rösblad, personal communication, April 10, 2000). The test required placing a pushpin under a table to match a target in each of four conditions: visual cues alone (visual), visual and tactile cues (visual proprioceptive), tactile cues alone (proprioceptive), and no cues (memory). Distance from the target was calculated and the mean absolute error scores for each condition were used. A lower score indicates better performance. This instrument was selected because it measures active proprioception and can be appropriately used with children without motoric limitations.

*In-Hand Manipulation (IHM).* The IHM (Pehoski, Henderson, & Tickle-Degnen, 1997a, 1997b) measures rotation and translation skills in children 3 to 7 years of age. Interrater reliability was reported for the simple rotation task as .81 (Pehoski et al., 1997a) and the two translation tasks as .82 and .79 (Pehoski et al., 1997b). The IHM is normed for children 3.0 to 6.6 years of age and adults (Pehosky et al., 1997a, 1997b) but the validity of the IHM has not yet been established.

The IHM yielded data about four variables: maturity of method used in simple rotation, speed of simple rotation, maturity of method used in finger to palm translation, and maturity of method used in palm to finger translation.

**Procedure**

The children were pretested on all outcome measures by investigators trained to administer the tests. Children were then randomly assigned to the three groups and intervention began within 2 weeks. The SM and TP groups received intervention four times per week for 5 weeks during regularly scheduled school hours. Each 40-minute session was...
divided into three segments with a 5-minute rest break between each segment resulting in 30 minutes of intervention per day. Total intervention time over the 5 weeks was 10 hours. The intervention was provided individually or in small groups (no more than three students per group) in quiet, private rooms at the schools. The rest breaks for both groups used nonhandwriting activities (e.g., therapist read to participants).

Four registered occupational therapists and one licensed physical therapist with pediatric experience provided the intervention. These five therapists were rigorously trained in an 8-hour training session to provide both forms of intervention. For SM intervention, activity guidelines and tool kits were issued. For TP intervention, activity guidelines, tool kits, and personalized practice booklets were issued. All materials were extensively reviewed with the therapists during the training sessions. Follow-up calls and visits were made by the experimenters to ensure continued adherence to the protocols.

Children were posttested at the conclusion of the intervention on all outcome measures. Two trained raters were used to score the THS. They achieved an interrater reliability of \( r = .89 \). One trained rater was used to score the DTVP-2 and the TMP. The IHM test was scored at the time of administration. Although the investigators were trained to administer and score this test, no formal measure of interrater reliability was obtained. All raters were blind to the child’s group assignment when scoring the outcome measures.

**Intervention Protocols**

**Sensorimotor group (SM).** A focus group of experienced school-based therapists provided advice on appropriate therapeutic intervention strategies for each of the four major sensorimotor components of interest in this study (visual perception, visual-motor integration, proprioception/kinesthesia, and in-hand manipulation). One of these components was targeted in each 10-minute segment, thus each sensorimotor component was addressed for 30 minutes over a week of four sessions (i.e., 2.5 hours total intervention time for each sensorimotor component during the entire study). Treating therapists were supplied with a toolbox of games, activities work sheets, equipment, treatment ideas for each component, as well as the schedule for rotation of activities. Treating therapists were experienced in pediatrics and were familiarized with the treatment activities during prestudy training sessions. The rotation schedule provided the framework to address specific sensorimotor components. However, the treating therapists were permitted flexibility to choose the actual activity used during each session from the list supplied and to vary the format, order, and materials used in the interventions to keep the participants engaged (Table 2).

**Therapeutic practice group (TP).** Handwriting practice books were prepared for each participant in the TP group. These books included work sheets to practice dictated and copied handwriting as well as writing from memory. Participants were given a workbook that matched their current writing method (manuscript or cursive) and style of instruction (D’Nealian, Zaner-Bloser, or Palmer). The intervention was designed using current motor-learning strategies (Schmidt & Wrisberg, 2004) to promote long-term learning of handwriting skill. The 30-minute session was divided into three 10-minute segments and different letters were the focus for each week (Table 3). The three 10-minute segments included work-sheet activities, real-life writing, and writing for fun. These three segments were presented in random order so that the handwriting practice schedule was randomized rather than blocked. The real-life writing assignments provided real contexts by incorporating actual class assignments whenever possible. Thank you letters, recipes, journal writing, and so forth were also used. Participants used a variety of pens, pencils, and unusual papers (i.e., white pen on black paper, gel pens, mechanical pencils, etc.) to vary the task constraints. Therapists gave feedback that provided the participants with knowledge of their results by summarizing their performance and delivering it at random times during the sessions. At the end of

<table>
<thead>
<tr>
<th>Table 2. Sensorimotor Treatment Group Protocol</th>
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<tbody>
<tr>
<td>Component</td>
</tr>
<tr>
<td>Visual Perception</td>
</tr>
<tr>
<td>Visual-Motor Integration</td>
</tr>
<tr>
<td>Kinesthesia/Proprioception</td>
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<tr>
<td>In-Hand Manipulation</td>
</tr>
</tbody>
</table>

*Note. Address the components as noted and repeat the schedule for each week of the study.*

**Suggested Activities for Each Component**

**Visual Perception**

Activities included: visual-closure, visual memory, figure ground and spatial relationships work sheets, word find exercises, parquetry blocks, and tangrams.

**Visual-Motor Integration**

Activities included: making shapes in bags of sand (do not use letters or numbers), cutting, pasting, tracing activities, and Origami designs.

**Kinesthesia/Proprioception**

Activities included: weight bearing through upper extremities to stimulate proprioceptors, eyes closed activities (Simon says, bilateral activities, close eyes and touch fingers), scooter board, lining up cans by weight.

**In-Hand Manipulation**

Activities included: putting two toys in bags (double bag them) and tell apart by feel, using chopsticks to pick up objects, playing with marbles.

**Work Sheets**

A variety of work sheets were available to students including hidden pictures, visual memory challenges, mazes, dot-to-dot pictures, word searches, similar and different pictures, and finishing a pattern (\( \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \)).

Table 3. Therapeutic Practice Group Protocol

<table>
<thead>
<tr>
<th>Session</th>
<th>Manuscript (U/L Case)</th>
<th>Cursive Letters (U/L Case)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C, A</td>
<td>I, T</td>
</tr>
<tr>
<td>2</td>
<td>D, O</td>
<td>U, W</td>
</tr>
<tr>
<td>3</td>
<td>G, Q</td>
<td>E, L</td>
</tr>
<tr>
<td>4</td>
<td>E, S</td>
<td>A, D</td>
</tr>
<tr>
<td>5</td>
<td>L, H</td>
<td>G, O</td>
</tr>
<tr>
<td>6</td>
<td>R, N</td>
<td>G, Q</td>
</tr>
<tr>
<td>7</td>
<td>M, U</td>
<td>R, S</td>
</tr>
<tr>
<td>8</td>
<td>B, P</td>
<td>B, F</td>
</tr>
<tr>
<td>9</td>
<td>F, T</td>
<td>J, P</td>
</tr>
<tr>
<td>10</td>
<td>I, J</td>
<td>H, K</td>
</tr>
<tr>
<td>11</td>
<td>Y, Z</td>
<td>M, N</td>
</tr>
<tr>
<td>12</td>
<td>V, W</td>
<td>V, X</td>
</tr>
<tr>
<td>13</td>
<td>X, K</td>
<td>Y, Z</td>
</tr>
<tr>
<td>14</td>
<td>Months/Days</td>
<td>Months/Days</td>
</tr>
<tr>
<td>15</td>
<td>U/L Case Dictated</td>
<td>U/L Case Dictated</td>
</tr>
<tr>
<td>16</td>
<td>Color and number words</td>
<td>Color and number words</td>
</tr>
<tr>
<td>17</td>
<td>Numbers: copied and dictated</td>
<td>Numbers: copied and dictated</td>
</tr>
<tr>
<td>18</td>
<td>Names</td>
<td>Names</td>
</tr>
<tr>
<td>19</td>
<td>All letters U/L Case (memory)</td>
<td>All letters U/L Case (memory)</td>
</tr>
<tr>
<td>20</td>
<td>Therapist Choice</td>
<td>Therapist Choice</td>
</tr>
</tbody>
</table>

Note. U/L = upper/lower.

Work sheet portion (10 minutes):
Work sheets in the manuals as described above.

Real-life writing (10 minutes):
Teachers may supply actual assignments, or could be generated by the occupational therapist. Activities included: writing a thank-you note, completing an invitation to a party, preparing a grocery list, writing in their daily planner, or completing journal entries.

Writing for fun (10 minutes):
A variety of pens, pencils, papers are provided for students to write anything they wish. Materials are self-selected from those presented each day. Materials should be varied so students have an opportunity to use all of them.

For all sessions:
Students should be encouraged to write for the entire 10-minute period. Give summed feedback about performance at random times during the session. Students should be encouraged to identify best work and compare with exemplar.

each 10-minute segment, metacognitive self-evaluation skills were targeted by asking the children to identify their best handwriting in each 10-minute segment and to explain how it was the same or different from the exemplar.

Therapists were supplied with a toolbox including a collection of age-appropriate real-life writing ideas; a variety of types of pens, pencils, and markers; and an assortment of writing paper. Treating therapists were experienced in pediatrics and were familiarized with all aspects of the treatment protocol during prestudy training sessions.

Control Group. The children in this group received no intervention and attended their normal classroom activities. They participated in both pretest and posttest evaluation sessions at the same time as the children in the intervention groups. All children in all groups participated in whatever normal handwriting activities or assignments were required by their classroom teacher during the length of the study.

Data Analysis

All statistical tests were performed using SPSS 12.0 and are reported here by research question. The significance level was set at .05. To determine if handwriting changed due to the intervention received (question one), a repeated measures analysis of variance (ANOVA) was performed on the difference scores (posttest–pretest). The three handwriting scales (memory, dictated, and copied) were used as the within-subjects factor and group as the between-subjects factor. This analysis was chosen because the three handwriting scales are treated as variants of the same construct (handwriting performance) that are measured using the same outcome measure. An effect size index ($f^2$) was also calculated to estimate the strength of any treatment effects and to guard against possible type II errors using the formula $f^2 = \frac{SS_b}{SS_e}$ (Portney & Watkins, 2000).

Each of the four sensorimotor components was analyzed separately to determine if there was an effect of intervention on the sensorimotor component scores (question two). Visual perception (motor-reduced) and visual-motor integration measures yielded a single composite score for each variable. Change in performance on these two variables was tested using repeated measures ANOVAs with the time of testing (pre and post) as the within-subjects factor and the intervention group as the between-subjects factor.

Because the TMP yielded four subtest scores, the proprioception scores were treated differently. Since there is no published precedent to combine these scores into a single score for each variable, a repeated measures ANOVA was calculated on the difference scores (post–pre). The subscale change scores were used as the repeated measure (within subject factor) and the intervention group was used as the between subject factor. This analysis was selected for two reasons. First, because all of the subscales were completed by the same participant, the subscale scores are related to each other in some way. Including the subscale scores as the repeated measure factor allows the dependency of the data to be factored into the analyses. And second, using a single ANOVA for all subscale scores is more efficient and reduces the likelihood of making a type I error due to multiple analyses. As mentioned previously, the repeated measures ANOVA is appropriate since each subscale is treated as a variant of the same construct (proprioception) and was measured with the same instrument.

The in-hand manipulation variable yielded four scores: simple rotation, simple rotation speed, finger–palm translation, and palm–finger translation. The simple rotation task was scored as outlined in Pehoski et al. (1997a) by rating the maturity of method used to pick up and rotate the pegs on a 3-point ordinal scale (1 = mature, 3 = immature). The
percentage of time the participants used each method during the rotation task was calculated. The simple rotation speed was measured by recording the time used in turning over and replacing the pegs. The translation tasks (finger to palm and palm to finger) were scored as outlined in Pehoski et al. (1997b) by rating the maturity of method used to hold and manipulate multiple pegs on a 4-point ordinal scale (1 = mature, 4 = immature). A total method score for each of the two translation tasks (finger to palm and palm to finger) was calculated using the mean percentage that each method was used over all four trials. Only the mature method scores were used in statistical analyses.

Separate repeated measures ANOVAs were performed on the simple rotation speed and the simple rotation and finger to palm translation and palm to finger translation data. The time of testing (pre–post) was the repeated factor and the group was the between-subjects factor. Separate analyses were chosen for these data since these data represent related but distinct measures of speed and quality of movement.

Results

Question One: Did children’s handwriting performance change due to the type of intervention they received?

There was no interaction effect between group and difference in handwriting from pre- to posttest: $F(2, 32) = .209, p = .81$; effect size ($f^2$) = .11. When all three handwriting scales were considered together, there was a main effect for group: $F(2, 32) = 8.44, p = .001$; effect size ($f^2$) = .72. A comparison of the means for the three groups showed a significant difference in the mean scores between the sensory motor group and the therapeutic practice group: $p = .001$. Unexpectedly, these two groups changed in opposite directions. When all three handwriting scales are collapsed, there is a 95% level of confidence that the handwriting performance of group 1 (SM) declined between 3 and 14 points. Conversely, the handwriting performance of group 2 (TP) increased between 1 and 12 points. Neither intervention group was significantly different statistically from the control group (group 3). Descriptive data for each group appears in Table 4.

Question Two: Did children’s sensorimotor component function change due to the type of intervention they received?

Visual perception (motor-reduced). At pretest, 75% of the participants scored below average compared with their peers ($M = 33.10, SD = 23.02$). There was no interaction between the intervention group and visual perception (motor-reduced) scores: $F(2, 34) = .815, p = .451$; effect size ($f$) = .22. However, there was a statistically significant main effect for motor-reduced visual perception: $F(2, 34) = 4.247, p = .023$; effect size ($f$) = .50, showing that visual perception (motor-reduced) improved in all three groups from pretest to posttest. A comparison of the means for the three groups showed a significant difference in improvement between the SM group and the control group ($p = .02$). The SM group improved more than the TP group, but not enough to reach statistical significance: $p = .362$.

Proprioception. The participants’ pretest proprioception scores fell within one standard deviation of the mean reported for the normative sample (B. Rösblad, personal communication, April 10, 2000). Some of the children’s scores fell below the mean for their age group on some subtests, but no clear trend in the scores was apparent. Proprioception scores did not change significantly from pretest to posttest for any of the groups: $F(2, 29) = 1.30, p = .29$; effect size ($f$) = .30.

In-hand manipulation. At pretest, all of the participants used mature methods of simple rotation less frequently (71%) than the published normative data for 6.6-year-olds (approximately 85%). Norms are not available for older children; however, normative adult data show mature methods of rotation are used approximately 90% of the time by adults (Pehoski et al., 1997a). At pretest, the participants were slower on rotation tasks ($M = 27.0$ sec, $SD = 7.94$) compared with the norms for 6.6-year-olds ($M = 22.0$ sec, $SD = 3.40$) and adults ($M = 20.0$ sec, $SD = 2.27$). None of the groups changed significantly between pretest and posttest on either use of the mature method: $F(2, 33) = 1.38, p = .27$; effect size ($f$) = .29, or speed: $F(2, 33) = 1.22$.
Effect of Intervention on Handwriting

For this sample of typically developing children with handwriting difficulties, therapeutic practice had a positive, albeit modest impact on children’s handwriting after a relatively short period of intervention. Handwriting practice reported in the literature takes different forms, such as work sheets as part of academic instruction (Rutberg, 1998) or work sheets with feedback (Sudsawad et al., 2002). The therapeutic practice sessions in this study were conducted in small groups of 2 to 3 children with direct therapist involvement. That is, although work sheets were used as part of the intervention, children were never asked to work on them unattended. Therapists provided appropriate feedback that was systematically timed to give the children summary knowledge of their performance. Practice schedules were designed to be random rather than blocked. The task constraints were deliberately varied, and the students’ metacognitive self-evaluation was consciously promoted. These results support those of Ste-Marie, Clark, Findlay, and Latimer (2004) that demonstrated therapeutic practice, based on principles of motor-learning, had a beneficial effect on handwriting performance.

The finding that handwriting performance declined in the SM group was unexpected. Unfortunately, this study took place at the end of the school year and the children went home for the summer making further testing impossible. At the conclusion of the study, the activities used in both intervention groups were reviewed by the focus group of consulting occupational therapists. No activities were used that could explain the decrement in performance of the SM group. It is possible that instrumentation error may explain this finding. The THS has established internal reliability but no test–retest reliability. On the other hand, if these results were due to measurement error, a wide fluctuation in scores across all children with no discernable difference between the groups would be expected.

The means of the individual handwriting scales by group (Table 4) show that the largest improvements in handwriting performance in the TP group were in the dictated (M = 5.97) and copied scales (M = 6.7). Improvement on the memory scale was smaller (M = 3.6). Close analysis of the treating therapist’s records reveal that dictated and copied handwriting practice dominated the interventions sessions, with less time spent on practicing handwriting from memory. It appears that the students improved the most on those forms of handwriting that received the most practice.

In summary, when all of the handwriting scales were collapsed, the effect of group on handwriting change was both statistically significant and clinically strong (effect size; f = .72). In part these findings may reflect the large range of difference scores created when the TP group scores increased and the SM group scores declined. Yet, it also appears that therapeutic practice resulted in demonstrable improvement in handwriting performance for some, but not all children in the TP group. The decline in handwriting performance for children in the SM group was not expected and remains unexplained. Overall, the control group did not change during the course of the study. The trends noted in this study are strong enough to warrant further investigation.

Effect of Intervention on Sensorimotor Components

As noted earlier, the sensorimotor components studied [visual perception (motor-reduced), visual-motor integration, proprioception, and in-hand manipulation] were selected because they were believed to have some relationship with handwriting. Since one of the selection criteria for participation in the study was dysfunctional handwriting,

\[ p = .31; \text{effect size } (f) = .27. \]
At pretest, the participant sample used the mature method of finger to palm translation on 49% of the trials, which places them between the rate for 6.6-year-olds (approximately 10%) and adults (100%) (Pehoski et al., 1997b). However, the participant sample used the mature method of palm to finger translation much less frequently (17%). This is contrasted to the mature method of palm to finger translation norms of 5% for 6.6-year-olds and 100% for adults.

Finger–palm translation scores changed from pretest to posttest. There was a significant interaction between time of testing and group: \( F(2, 35) = 4.28, p = .02; \text{effect size } (f) = .49 \) as well as a significant main effect for time of testing: \( F(1, 35) = 10.60, p = .003; \text{effect size } (f) = .55 \). Post hoc tests revealed that all three groups used the mature finger to palm translation method more frequently at the end of the study than at the beginning. The SM group (group 1) improved more than the other two groups, but this difference failed to reach statistical significance.

On palm–finger translation, there was no interaction between the time of testing and group: \( F(2, 35) = .91, p = .41; \text{effect size } (f) = .21 \). However there was a significant main effect for time of testing: \( F(1, 35) = 8.98, p = .01; \text{effect size } (f) = .24 \). Participants in all 3 groups used the mature method of palm–finger translation more frequently at posttest than they did at pretest. Although the SM group (group 1) improved more than the other two groups, this difference failed to reach statistical significance.

Discussion

Effect of Intervention on Handwriting

In summary, when all of the handwriting scales were collapsed, the effect of group on handwriting change was both statistically significant and clinically strong (effect size; \( f = .72 \)). In part these findings may reflect the large range of difference scores created when the TP group scores increased and the SM group scores declined. Yet, it also appears that therapeutic practice resulted in demonstrable improvement in handwriting performance for some, but not all children in the TP group. The decline in handwriting performance for children in the SM group was not expected and remains unexplained. Overall, the control group did not change during the course of the study. The trends noted in this study are strong enough to warrant further investigation.

Effect of Intervention on Sensorimotor Components

As noted earlier, the sensorimotor components studied [visual perception (motor-reduced), visual-motor integration, proprioception, and in-hand manipulation] were selected because they were believed to have some relationship with handwriting. Since one of the selection criteria for participation in the study was dysfunctional handwriting,
impairment in these sensorimotor components was logically expected. None of these children had identified educational needs and therefore did not qualify for occupational therapy services. The assumption that these children would demonstrate sensorimotor component impairment was generally supported, because, at pretest, most of the participants fell below the norm for their age group in three out of four sensorimotor components.

Visual perception (motor-reduced). The children began this study with some impairment in visual perception and improved at the end of the study, regardless of intervention group. As expected, the SM group improved in visual perception more than the control group. Although not statistically significant, the SM group also showed a trend towards greater improvement in visual perception than the TP group. Because the SM group received intervention aimed at improving visual perception, this improvement was expected.

By measuring visual perception without requiring a motor response, this study provided support for the assumption that children with dysfunctional handwriting would also have impaired visual perception. There is also some support for the assumption that visual perception can be improved through intervention in a relatively short period of time.

Visual-motor integration. Nearly 75% of the children began this study with some degree of visual-motor integration impairment. However, intervention failed to improve visual-motor integration skills. It is possible that the intervention activities did not address visual-motor integration adequately or the intervention time was too short. Perhaps the relationship between visual-motor integration and handwriting is complex and involves additional factors or processes as of yet unknown.

Proprioception. About one third of the children (n = 11) had individual scores that fell below the mean for their age group, however the majority of the children did not have proprioceptive deficits. Because the TMP lacks established reliability, measurement error is a possibility. Sudsawad et al. (2002) used a sample of typically developing children with handwriting and kinesthetic dysfunction that implies that the two coexist. The findings of this present research did not support this assumption. The difference might be explained by the fact that Sudsawad used a passive measure of proprioception and this current research used an active measure. Active proprioception measures are believed to be a more valid measure of proprioception that contributes to movement (Röslad, 1995). Finally, since most of the participants did not have proprioceptive deficits, it is not surprising that no significant change in proprioceptive functioning was detected over the course of the study.

In-hand manipulation. At the start of this study, the participants generally used immature methods and had longer speeds for simple rotation than the oldest normative group of children (6.6 year olds). It is unknown how impaired these in-hand manipulation skills compare to those of typically functioning children of their own age. It may be possible that the immature methods of rotation are not as efficient as mature methods and therefore result in longer speeds needed to complete the task. At pretest, this sample demonstrated impaired simple rotation skills. Although the SM group received intervention aimed at improving in-hand manipulation skills, no change was noted. Thus, this study failed to demonstrate that simple rotation skills would improve with intervention.

The mature method of finger–palm and palm–finger translation was used more frequently than 6.6-year-olds but less often than adults. There were significant changes from pretest to posttest in the frequency of using the mature method for both translation tasks. The finding that all groups improved from pretest to posttest suggests a practice effect may have occurred. The time between pretest and posttest was relatively short (5–6 weeks) and test–retest reliability of the dependent variable has not yet been established. Although all groups improved, the data suggest a trend toward greater improvement in the SM group (group 1), thus providing tentative support for the assumption that translation skills would improve with intervention.

Because norms for the IHM are not available for the age groups between 6.6 and adults, these data must be cautiously interpreted. It could be argued that children who are older could be expected to use the mature method as often as the normative 6.6-year-olds. Yet, as Case-Smith (1995) points out, young children use a variety of methods to maintain their interest in the activity. Thus measuring consistency of method and speed may not have been the most appropriate measures of in-hand manipulation skill. Little is known about the developmental sequence of acquiring in-hand manipulation skills after 6.6 years of age. Further research is needed to determine developmentally appropriate methods of measuring in-hand manipulation, the level of function that represents clinical significance, and to determine how impairments in in-hand manipulation can be most effectively remediated.

In summary, these participants demonstrated impairments in three of the four sensorimotor components at the beginning of the study. This finding offers support for the assumption that deficits in visual perception (motor-reduced), visual-motor integration and in-hand manipulation skills are present with dysfunctional handwriting even in this sample of “typically developing” children. However,
the impact of intervention on improving performance in these sensorimotor components was less strong. Improvement was demonstrated in only two areas: visual perception (motor-reduced) and in-hand manipulation—translation skills. Although one effect size was moderate (visual perception, motor-reduced) the effect sizes were generally small. Since no power analysis was conducted prior to the study, it is possible that the small sample size may account for the failure of the results to reach statistical significance. Additional research is needed to determine the optimal intervention time and activities for all of these sensorimotor components.

This research supported the assumption that dysfunctional handwriting and impairment in three sensorimotor components [visual perception (motor free), visual-motor integration, and in-hand manipulation] coexisted in children without identified educational needs. Further, sensory motor intervention was effective in improving function in some of these sensorimotor components. Yet there was little support for the assumption that a causal relationship exists between these sensorimotor components and handwriting. The participants who received sensorimotor intervention did experience some improvement in sensorimotor component function but, at the same time, their handwriting performance declined. Conversely, children who received therapeutic practice improved in handwriting performance whereas their sensorimotor component function remained unchanged. Therapeutic practice designed following principles of motor-learning and delivered as an intensive manner over 10 hours, resulted in modest improvements in children's handwriting.

Limitations

This study had several limitations that affect the generalizability of the results. The sample size was small and represented children without a known educational need or diagnosis. The groups were not equal in number and the control group was smaller than the two intervention groups, so the statistical analyses need to be conservatively interpreted. The control group received ordinary instruction during the course of the study. The control group students did not receive the individual attention from an adult that the other participants received. However, because the intervention groups’ handwriting scores changed in opposite directions (sensory motor scores went down and therapeutic practice scores went up), it is unlikely that adult attention had any noticeable positive effects.

Handwriting performance is likely affected by other variables that were not included in this study. The children were in all phases of developing handwriting competence. A few children had started cursive instruction, but most were using manuscript. Children were not asked to assess their own handwriting mastery, so motivation for change was not assessed. Although it appeared that the children made an honest attempt to form the letters “correctly” on the test, their name was written on the test booklet with considerable individuality. Using handwriting style as an expression of personality was not explored in this study. Other variables such as attention, speed of thinking, interest, and so forth were not assessed.

Unfortunately, the amount of time spent on handwriting instruction at each school was not measured. Anecdotal information suggested that little formal instruction time was devoted to handwriting. Generally teachers used work sheets and individual practice with delayed written feedback. There were no differences between schools on pretest handwriting scores, suggesting that instruction was similar across all of the schools.

The intervention in this study was delivered using pull-out sessions over 5 weeks (total of 10 hours). Previous research showed a positive treatment effect in as little as 2 hours (Stenkar, 1997); however, other intervention has continued for the entire school year (Oliver, 1990). It is important to note that a positive, if modest, intervention effect was achieved in a short, intensive time frame in this study. Variations of the intervention model (i.e., in-classroom instruction, longer intervention period, etc.) were not examined.

In this study, therapeutic practice and sensorimotor treatment were isolated as separate interventions to try to determine the contribution of each to improving handwriting in a systematic manner. The treating therapists in both intervention groups were free to alter the daily activities to meet individual student needs within the overall prescribed protocol; however, much work remains to understand which interventions are appropriate for which types of handwriting problems. The work of Schwellnus and Lockhart (2002) is a good start in that direction.

Clinical Implications

Despite the limited empirical evidence that sensorimotor components are related to handwriting, they are included as key areas in handwriting evaluations (Amundson, 1992) and are recommended as standard practice in occupational therapy textbooks (Amundson, 1992; Amundson & Weil, 2001; Tseng & Chow, 2003). By contrast, the findings of this current study call into question prevailing clinical assumptions about relationships between sensorimotor components and handwriting intervention. If improvement in sensorimotor function only is desired as the end
goal of treatment, then sensorimotor treatment may be an appropriate intervention for handwriting dysfunction. Some of the children in this study did experience improvement in sensorimotor component function after sensorimotor treatment. However, there is no indication from this study that improvement in sensorimotor component function improved handwriting. Indeed, the reverse was found. This study found that therapeutic practice, carefully and systematically structured and implemented using motor-learning principles, was effective in improving handwriting with typically developing children with handwriting dysfunction.

It could be argued that the priority for occupational therapy services for typically developing children with only handwriting dysfunction is lower than for those children who have multiple needs. Yet modest, but significant, improvement in handwriting was noted with a relatively minimal amount of intervention time. It could also be argued that practice is an inappropriate intervention for occupational therapists to provide. If practice consists of unsupervised mass-produced work sheets, we would agree. But therapeutic practice, thoughtfully constructed and delivered, incorporating what is known about learning a motor skill, fits within occupational therapy’s domain by helping children to master the important occupation of handwriting.

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References


