The Influence of Ergonomic Factors and Perceptual-Motor Abilities on Handwriting Performance

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Handwriting is an important skill for school-aged children. A student’s ability to produce fluent and legible writing is important for expressing, communicating, and recording ideas as well as for educational development (Phelps, Stempel, & Speck, 1985). Handwriting problems interfere with the child’s ability to show what he or she knows. The child with handwriting problems often cannot finish assignments on time; because writing is difficult, the child may try to complete a written assignment in as few words as possible. When a child has to focus on the mechanical aspects of writing, he or she cannot fully attend to the content of information. Thus, there is a tradeoff between concentration on learning and concentration on writing (Levine, 1985, 1987; McHale & Cermak, 1992).

Problems in handwriting are frequent reasons why children in the public schools are referred to occupational therapy (Cermak, 1991; Reisman, 1991; Schneck & Henderson, 1990). This paper reviews current research regarding ergonomic and perceptual-motor contributions to handwriting and discusses implications for remediation. It is proposed that understanding the mechanisms and factors that underlie and contribute to handwriting performance will help therapists to design more effective treatment programs.

Ergonomic Factors

Ergonomics, the study of work, involves the interaction and the fit between human capabilities and the demands of a job (Smith, 1989). In this paper, the job is handwriting. Two factors, pencil grip and pressure on the writing instrument or surface, are examined.

Pencil Grip

Pencil grip is an aspect of handwriting that has been addressed by occupational therapists who work with children with writing problems (Schneck & Henderson, 1990). Although the dynamic tripod grip is generally encouraged by educators and therapists, numerous variations of grip exist. These variations have often been seen in children with disabilities who have poor handwriting. However, it is not clear to what extent an atypical grip contributes to poor handwriting (Schneck, 1991; Ziviani, 1987).

Most children between the ages of 4 and 6 years develop dynamic tripod grips (Rosenblom & Horton, 1971; Schneck, 1990; Schneck & Henderson, 1990). As children grow older, they seem to refine the dynamic tripod grip. Ziviani’s (1983) results place that development between the ages of 7 and 14 years. She used four components to measure grip: degree of index finger flexion, degree of forearm pronation and supination, number of fingers used on the pencil shaft, and thumb and forefinger opposition. However, she observed developmental
Pressure on Writing Instrument and Surface

Handwriting requires well-integrated movements of different body parts. The delicate movements of the fingers must be coordinated with fixation and release at the wrist and elbow. At the same time, the shoulder and trunk must be stabilized (Ziviani, 1987). It is thought that a child with low muscle tone uses more effort to hold not only the head and body up against the pull of gravity, but also the writing implement. Clinicians have observed that, for children with low muscle tone, the pressure of lines in their writing is often light and their handwriting deteriorates over time. Moreover, these children tend to rest their heads on their hands or arms while sitting at a desk, which may affect their perception of what they have written and result in failure to correct (Gajraj, 1982).

Currently, much of the discussion of the effect of low muscle tone on legibility of handwriting comes from clinical observations. Research with children that specifically addresses the extent to which low muscle tone affects legibility of handwriting has not been reported.

In addition to the influence of low muscle tone on handwriting, it seems logical that handwriting would suffer from muscle stress and tension that impede the free-flowing movements necessary for legibility. Evidence suggests that tension is an important factor affecting handwriting performance. Herrick and Otto (1961) have pointed out that there are actually three measures of pressure: those of the fingers on the barrel of the pen, of the pen on the writing surface, and of the hand resting on the writing surface. Harris and Rarick (1957, 1959) have studied the point pressure on the writing surface as it relates to speed and legibility in handwriting. Their findings revealed that force variation had a closer relationship with legibility and speed in handwriting than had absolute point pressure (Harris & Rarick, 1957, 1959). Their conclusion was that increased speed leads to increased variation in force application such that motor coordination is disrupted and handwriting legibility is negatively affected. On the basis of Harris and Rarick’s studies, it appears that handwriting teaching should be individualized in terms of each student’s particular motor control ability so that handwriting speed and level of pressure can be optimally developed at the student’s pace.

The influence of relaxation training on handwriting performance has been studied in various groups. Carter and Synolds (1974) found that relaxation training improved handwriting quality in boys with minimal brain injuries, and the improvement transferred to nonexperimental situations. However, no control group was included for comparison. Jackson and Hughes (1978) supported Carter and Synolds’ findings by using a relaxation training program on a group of typical fourth graders rated as poor handwriters. Hughes, Jackson, DuBois, and Ervin (1979) had similar findings. They concluded that relaxation training, when carried out in a group, may be more effective for improving handwriting skills than a biofeedback training program given individually. Similar
results were obtained by Jackson, Jolly, and Hamilton (1980) who found that relaxation training combined with handwriting suggestions and traditional handwriting teaching was the most effective method for improving poor handwriting.

In summary, the research findings seem to imply that relaxation training, when administered by itself or as part of a larger program, can lead to improved handwriting performance by reducing muscle tension. Nevertheless, because the relaxation training used by Carter and Synold (1974) and Jackson and Hughes (1978) incorporated not only relaxation but also handwriting suggestions, it is not clear whether the improvement resulted from relaxation, the handwriting suggestions, or both. Thus, further research is needed to examine the exact effect of relaxation training on the reduction of muscle tension and the relationship between muscle tension, muscle tone, and handwriting performance.

Implications for Practice

“Both occupational therapy and ergonomics are concerned with the individual’s adaptation to and interaction with the physical environment” (Smith, 1989, p. 128). In ergonomics, the goal is to accommodate the design of the workplace and the job to the worker’s capabilities (Smith, 1989). In this sense, a variety of adaptations can be considered to help the child with handwriting within the school environment. These may include adaptations to the environment (school setting) such as a change in desk or seat size, use of vertical writing surfaces, use of a tape recorder to reduce the demands of writing, or use of a word processor to alter the perceptual-motor demands of graphomotor production. Intervention may also involve use of different or adapted tools such as an adapted pencil grip, markers instead of pencils, wide instead of narrow ruled paper, or graph paper. Ergonomic literature, primarily with adults, has shown that factors such as the length, diameter, and shape of hand tools determine their optimal efficiency (Bruening & Beaulieu, 1990; Johnson, 1991). Benbow (in press) has fully discussed a variety of adaptations to enable a better match between the child’s abilities and the task of handwriting. Finally, changes may be made in job design, such as having the child write two short papers rather than one long paper.

The Role of Perceptual–Motor Abilities in Handwriting Performance

The reasons that some children find it difficult to produce clear, legible handwriting are many and complex. Impaired kinesthetic feedback, poor visual perception, and problems in visual–motor integration, fine motor skills, and motor planning are factors often cited in the literature to account for handwriting difficulties (Alston & Taylor, 1987; Gaddes, 1985; Levine, 1987; Lindsey & Beck, 1984). The role of each factor is reviewed and discussed.

The Role of Kinesthetic Perception

Kinesthetic perception is the sense of position and movement of limbs and body. Through kinesthesia, without vision, we perceive the position of our limbs relative to our body (Sage, 1984). Describing the role of kinesthesia in the acquisition and performance of handwriting, Laszlo, Bairstow, and colleagues suggested that kinesthesia plays two roles in handwriting performance: It provides ongoing error information and references for subsequent repetitions of the motor act. They further stated that a child who has difficulty perceiving or storing kinesthetic information will have difficulty not only with handwriting but also with improving performance through practice (Laszlo & Bairstow, 1984; Laszlo, Bairstow, & Bartrip, 1988; Laszlo, Bairstow, Bartrip, & Rolfe, 1988).

Levine (1987) addressed the adverse effect of impaired kinesthetic feedback on the pencil grip. In his discussion of low productivity in school-aged children, Levine suggested that three motoric priorities must be balanced in the process of handwriting: stable pencil grip, maximum maneuverability of the writing implement, and movement of the writing implement so that transmission of kinesthetic feedback is possible. Levine stated that these three priorities may interact negatively with each other to some extent. That is, mobility may be limited by increased stability, but an excess of mobility may interfere with some of the fine-tuned feedback.

According to Levine (1987), children may compensate for impaired kinesthetic feedback by developing an awkward, inefficient pencil grip. They establish a repertoire of contorted grips that exert excessive pressure on the pencil, which serves to provide increased kinesthetic feedback. The result of this compensation is an inability to attain the dynamic tripod grip, and, because of the need to constantly visually monitor their work, their writing becomes laborious rather than automatic. The lack of speed causes a proportional loss in the quantity of writing they are capable of. Levine, Oberklaid, and Meltzer (1981) noted that 20 of 26 children (77%) who were identified as having developmental output failure had awkward pencil grips. Schneck (1991) also supported the importance of kinesthesia in some aspects of handwriting. In her study, children with low grip scores and poor handwriting were the children with decreased kinesthetic feedback.

Ziviani et al. (1990) studied handwriting problems in a group of children with spina bifida and found that kinesthesia (as measured by the Kinesthesia Test of the Southern California Sensory Integration Tests [Ayres, 1972, 1980]), receptive language, age, and handedness accounted for 55% of the variability of the alignment of words, and that kinesthesia along with age accounted for 71% of the variability of letter formation.
Laszlo and Bairstow (1983) investigated the relationship between kinesthesia, as measured by the Kinesthetic Sensitivity Test, and skilled motor behavior. Two groups of children with low kinesthetic scores, as determined by the Kinesthetic Sensitivity Test, and a kinesthetically able control group, were pretested on kinesthetic acuity, kinesthetic memory, and certain drawing tasks. One group with kinesthetic impairment was trained over 6 days on kinesthetic acuity and memory tasks and on the drawing of a square, a diamond, and a triangle under a masking box. The second group with kinesthetic impairment was trained only on the drawing tasks over the 6 days. The control group also was trained on the drawing tasks. A comparison of pretest scores and scores on posttests indicated significant improvement on all three tests by the group receiving kinesthetic training, but not by the other two groups, with the exception that the control group had significant improvement on the kinesthetic memory tests.

During the second stage of the study, the second experimental group received training on the tests of kinesthetic ability, but was trained no further in drawing. Once this second training phase was completed, they were again given the tasks of copying a square, a diamond, and a triangle under the masking box. After kinesthetic training, their resulting drawing scores were significantly higher than the scores in the prior phase, which did not include kinesthetic training. The authors concluded that

These results confirm the notion that kinesthesia is necessary for the efficient performance and acquisition of skilled movements. In group 1, children trained on both drawing and kinesthetic tasks improved in drawing, while drawing training alone in group 2 did not lead to any improvement in the drawing skill of subjects in group 2. (1983, p. 419)

Although a control group was employed, no comparison was made between experimental and control groups. Instead, the investigators compared pretraining and posttraining scores for each group. On the basis of this type of comparison, extraneous variables such as maturation cannot be ruled out as competing explanations; thus, the improvement cannot be attributed solely to kinesthetic training. Moreover, the kinesthetic and drawing training resemble the tasks for posttest. The effect of practice may account for the improvement. Nonetheless, the $d$-indexes for Group 1 are substantially greater for kinesthetic memory and drawing tests than those for the other groups (see Table 1). Therefore, it appears that kinesthetic training affects kinesthetic memory and drawing performance. Taken together, the findings of Ziviani et al. (1990) and Laszlo and Bairstow (1983) appear to support the latter’s theoretical conception that kinesthetic input is important in the process of skilled movement such as handwriting (Laszlo & Bairstow, 1984; Laszlo, Bairstow, & Bartrip, 1988; Laszlo, Bairstow, Bartrip, & Rolfe, 1988).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Results of T-test on Pretraining Scores Versus Posttraining Scores in Kinesthesia and Drawing</th>
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<tr>
<td></td>
<td>Group 1</td>
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<tr>
<td>Kinesthetic acuity</td>
<td>2.19</td>
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<tr>
<td>Kinesthetic memory</td>
<td>3.49</td>
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<td>Drawing</td>
<td>3.55</td>
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The Role of Visual Perception

Although much writing has explored the relationship between visual perception and reading disabilities, the literature on the relationship between visual perception and handwriting is limited. According to Ayres (1958), handwriting is a visual-motor performance task of the upper extremities. Ayres did not directly postulate the process for learning handwriting skill, although she drew upon the work of Strauss and Kephart (1955) and addressed the importance of visual perception in the motor act. Strauss and Kephart (1955) considered it crucial to provide, through visual perception, a substantial and clearly structured pattern for the motor action to follow. In that way, better coordination could be achieved by the provision of better visual-perceptual stimulation. Furthermore, Strauss and Kephart believed that visual perception was used to give meaning to a pattern generated by proprioceptive perception.

In contrast, Laszlo and Bairstow (1984) assumed that by the time the child can write, he or she has a fully developed sense of visual shape discrimination. They argued that kinesthetic perception, rather than visual perception, contributes to ongoing error detection and correction programming. This argument stems from the fact that there is a temporal delay between programming the movement to write the letter and actually seeing it on the page.

Despite the limited amount of literature on the relationship between visual perception and handwriting, visual perception is the perceptual-motor skill examined most frequently in relation to handwriting. However, results have not provided convincing evidence for the contention that visual perception plays an important role in handwriting performance. Four studies have used a correlational design to investigate the role of visual perception in handwriting. Lewis and Lewis (1965) investigated the relationship between the types of handwriting errors and visual perception, as measured by the matching subtest of the Metropolitan Reading Readiness Test, in 354 nonrepeating first graders. Only a slight relationship between visual perception and the incidence of errors in
letter formation was demonstrated. The authors did not report how the data were analyzed or how the exact correlation was established.

Chapman and Wedell (1972) examined the relationship between reversal errors in children's handwriting and perceptual-motor abilities in a group of children aged 7.5 to 8.5 years. The Perceptual Quotients of the Frostig Developmental Test of Visual Perception (DTVP) (Frostig, 1964)—a test designed to measure the specific visual perceptual skills of eye-hand coordination, figure-ground perception, form constancy, position in space, and spatial relations—were significantly lower in the group of children with reversal errors. Among the subtests, only the Position in Space scores demonstrated statistically significant differences between children with and without reversal errors. However, the reliability of the individual subtests on the Frostig is inadequate for interpretation.

Yost and Lesiak (1980) examined the relationship between handwriting ability and performance on the DTVP in a group of 60 nonrepeating first graders. No significant relationship was found between good or poor handwriting ability and a Perceptual Quotient score (comparable to an IQ score) of above or below 90 on the DTVP. The validity of the study by Yost and Lesiak (1980) can be questioned because the DTVP has a strong motor component. Ziviani et al. (1990), in their study of handwriting problems in a group of 34 children with spina bifida, chose the Test of Visual Perceptual Skills (Nonmotor) (Gardner, 1982) because it acquired minimal motor responses. However, the role of visual perception in handwriting performance was not substantiated in their study.

The four studies with a correlation design, those of Yost and Lesiak (1980) and Ziviani et al. (1990) did not find significant correlations between visual perception and handwriting ability, whereas Lewis and Lewis (1965) and Chapman and Wedell (1972) found a slight relationship. Each study has its own limitations. No statistics were reported on the result of the relationship between error types and visual perception in the Lewis and Lewis study (1965). The study of Chapman and Wedell (1972) addressed only a specific aspect of handwriting performance, that is, reversal errors. The results of Yost and Lesiak (1980) were confounded by motor responses involved in the DTVP. The study by Ziviani et al. (1990) was on a specific population with spina bifida, a sample with known motor deficits that can affect handwriting. Their results cannot be generalized to other populations; thus, further research is warranted to provide cumulative data for examining the proposed role of visual perception in handwriting.

The Role of Visual–Motor Integration

Visual–motor integration is conceptualized as the ability to integrate the visual image of letters or shapes with the appropriate motor response (Beery & Buktenica, 1967; Sovik, 1975). Visual–motor integration is often defined operationally as the ability to copy geometric shapes. Beery (1982) suggested that the first nine figures in his Developmental Test of Visual–Motor Integration should be mastered before a child learns to write. The first nine figures are a vertical line, a horizontal line, a circle, a cross, a right-to-left diagonal, a left-to-right diagonal, an X, a square, and a triangle. Lindsey and Beck (1984) considered the ability to copy three shapes (circle, square, and triangle) as one of the writing subskills. In the same vein, Taylor (1985) stated that "if a pupil can manage to copy the circle, cross and square, he is in a position to learn to write most the letters with the exception of k, v, w, x, z." (p. 206). These authors agree that these basic shapes should be mastered before a child starts to learn handwriting.

The assumption that visual–motor integration plays an important role in handwriting gains support from two empirical studies (Sovik, 1975; Tseng, 1991). Tseng (1991) examined the relationship of a set of perceptual–motor measures to legibility of handwriting in a group of Chinese school-aged children. Results of regression analyses indicated that visual–motor integration as measured by the Developmental Test of Visual–Motor Integration (Beery, 1989) was the best predictor of legibility of handwriting and accounted for 30% of variance on legibility scores. Sovik (1975) examined this relationship with both American and Norwegian children and reported a similar finding.

Rubin and Henderson (1982) compared handwriting scores to scores on the Bender-Gestalt Test (Koppitz, 1975), a measure of visual–motor integration, between poor and good writers. The data indicated that poor writers were indeed considerably worse than good writers; however, the correlation between the children's Bender-Gestalt test scores and their handwriting scores was only moderate (r = .49), showing that poor copying ability is only moderately associated with poor handwriting. This finding suggests that handwriting is a complex skill and that deficiency in one aspect may not be sufficient to predict the degree of poor handwriting.

The Role of Fine Motor and Motor Planning Skills

In delineating the sequence and structure of handwriting competence, Taylor (1985) suggested that to hold and manipulate the writing tool efficiently presupposes fine motor coordination to some degree. Levine et al. (1981), in a study of low productivity in school-aged children, found that children with handwriting difficulty tended to have problems in fine motor tasks. In their study, 72% of children identified as having "developmental output failure" (low academic work output) were considered to have difficulty with fine motor tasks. They postulated that
uncoordinated finger movements can lead to diminished pencil control; this, they suggested, may result in writing that is "illegible and/or laborious, hesitant, and slow" (p. 20).

Rubin and Henderson (1982) examined the relationship between handwriting performance and fine motor skills as measured by five fine motor items of the Test of Motor Impairment (TMI) (Stott, Moyes, & Henderson, 1972). The poor writers were not significantly poorer at fine motor skills than the control children, but a greater variability of scores was noted among the poor writers. It should be noted that each item of the TMI has a limited range of scores, that is, either "below normal" or "normal." As a result, the test may not be sensitive enough to pick up differences.

According to Levine (1987), motor planning or praxis is important for skilled motor acts such as handwriting. Levine cited Luria (1980) as describing two forms of the problem of poor motor planning. One form of the problem is characterized by difficulty in formulating an ideomotor plan of what one intends to do. In the other case, it is possible to formulate the plan, yet there is difficulty in implementing it motorically because the central nervous system mechanisms responsible for executing the plan are disrupted. When either form of the problem exists, handwriting difficulties ensue.

Ziviani et al. (1990) addressed the role of motor planning in relation to handwriting performance in children with spina bifida. Motor planning, as measured by the Motor Accuracy Test (Ayres, 1972), was not associated with any legibility components or with writing speed. Although the Motor Accuracy Test includes a component of motor planning, it measures mainly eye-hand coordination. More recently, Tseng (1991) examined the contributions of a variety of perceptual-motor measures to handwriting in children from Taiwan through stepwise regression analyses. She found that the Finger Position Imitation Test (FiPIT) (Drucker, 1980), a test of motor planning, was the best and only significant predictor of legibility of poor writers. However, it only explained 10.3% of the variance in the legibility scores. It is likely that handwriting is such a complex skill that many variables contribute to or hinder performance.

Summary and Implications for Treatment
The role of visual perception shows little relationship to handwriting, whereas kinesthesia, visual–motor integration, and motor planning appear to be more closely related to handwriting. The differences in the outcomes of the studies reviewed here may be accounted for in part by the methodological inadequacies of many of the studies. Further examination of perceptual–motor factors and handwriting is warranted to provide cumulative data for validating the possible role of the underlying competencies in handwriting.

Most of the studies examining handwriting and perceptual–motor components of performance have been correlational. Authors have assumed that if there is a correlation between performance on the component and handwriting, that problems in the component underlie the handwriting problem, and that remediation of the component will result in improvement in handwriting. Although research has not shown these assumptions to be incorrect, the correlational type of research does not allow for these conclusions for several reasons. First, correlation does not mean causation. Thus, if children who have problems in visuospatial abilities also have problems in handwriting, it does not mean that the visuospatial deficit causes or underlies the handwriting problem, because another variable might affect both visuospatial ability and handwriting. Second, remediation of the visuospatial problems may or may not result in improved handwriting. Additional research is needed to directly examine this assumption. In their examination of the relationship between kinesthesia and writing, Laszlo, Bairstow, and colleagues have studied the effects of kinesthetic training on writing, and have provided models for this type of needed research (e.g., Laszlo & Bairstow, 1983). Their studies provide preliminary support for the assumption that improving kinesthetic perception will result in improved writing.

At this time, much of occupational therapists' work with remediation of handwriting deficits in children is based on clinical judgment and clinical reasoning. Although practice in handwriting is certainly one strategy, it may be more effective when paired with (a) teaching techniques that capitalize on the child's strengths, (b) remediation procedures that develop foundation or performance components, or (c) compensation methods. Cermak (1991) described several factors that can result in different types of handwriting problems and discussed intervention under three categories: demystification, bypass strategies, and direct intervention. Demystification involves explaining the problem to the child and his or her teachers. If the teachers understand the child's difficulty, they will not attribute poor handwriting to laziness and they will realize that when the child puts a lot of effort into the graphomotor aspects of writing, his or her ability to process the content of the information may be compromised.

Bypass strategies involve circumventing the problem. One strategy involves altering expectations so that demands are prioritized. For example, if the primary purpose of an assignment is content knowledge, then the handwriting on that assignment may not be graded, whereas another assignment may focus primarily on handwriting. Environmental manipulations may also facilitate task performance. These might include using graph paper to aid the child with spatial organization or providing adapted writing tools. Another example of a bypass or compensatory strategy would be the use of a
computer to minimize the handwriting demands. This strategy may require teaching the child word processing along with handwriting. Several articles have discussed the use of word processors for improving children’s writing (e.g., Glazer & Curry, 1988; Hunter, Jardine, Rilstone, & Weisgerber, 1990; Majsterek, 1990; Outhred, 1989). Many of the ergonomic principles, such as adapting the environment, would be categorized under this type of intervention.

The third and final approach is direct intervention. The goal of treatment is for the child’s writing to become automatic and fluid so that the child does not have to think about letter formation and can produce an adequate volume of work in an expected period of time without undue fatigue. Remediation of handwriting should always be done in conjunction with the child’s teacher so that a consistent approach to teaching handwriting is used. Practice with letter formation is certainly a necessary component of remediation. In addition, the child’s motor skills and sensory processing abilities that contribute to and are considered to underlie good handwriting are important to consider. For example, some children with poor handwriting have inadequate somatosensory perception, which may be manifested in finger identification and tests of kinesthetic perception. The child who does not adequately process somatosensory information may overly rely on the visual system and position his or her head close to the paper to visually monitor the hands. To try to increase somatosensory feedback, the child may develop poor pencil grasp, characterized by stabilization of the distal joints. Although this may be adequate for small amounts of writing, it produces fatigue when the writing demands are great (Levine, 1985). Recently, several studies have discussed the importance of a kinesthetic approach in the remediation of handwriting problems in children. Laszlo et al. (Laszlo & Bairstow, 1985; Laszlo, Bairstow, & Bartrop, 1988) described specific training of kinesthetic perception. Benbow (1990; in press) also has supported the use of a kinesthetic approach for teaching handwriting. She has emphasized that kinesthetic processing is even more important for cursive than for manuscript writing.

Handwriting is a complex task, and various factors are related to skilled handwriting. Various procedures have been suggested by educators and therapists to facilitate handwriting. These procedures need to be more fully examined to determine whether specific approaches are more effective for remediating certain types of handwriting errors.

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