
Analysis of Proximal and Distal Muscle Activity During Handwriting Tasks

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KEY WORDS

- electromyography
- handwriting
- Jewish
- muscle activity
- pediatrics

OBJECTIVE. In this study we sought to describe upper-extremity proximal and distal muscle activity in typically developing children during a handwriting task and to explore the relationship between muscle activity and speed and quality of writing.

METHOD. We evaluated 35 third- and fourth-grade Israeli children using the Alef–Alef Ktav Yad Hebrew Handwriting Test. Simultaneously, we recorded the participants' upper trapezius and thumb muscle activity by surface electromyography. Using the coefficient of variation (standard deviation divided by mean amplitude) as a measure of variability within each muscle, we analyzed differences in muscle activity variability within and between muscles.

RESULTS. The proximal muscle displayed significantly less variability than the distal muscles. Decreased variability in proximal muscle activity was associated with decreased variability in distal muscle activity, and decreased variability in the distal muscles was significantly associated with faster speed of writing.

CONCLUSION. The lower amount of variability exhibited in the proximal muscle compared with the distal muscles seems to indicate that the proximal muscle functions as a stabilizer during a handwriting task. In addition, decreased variability in both proximal and distal muscle activity appears to be more economical and is related to faster writing speed. Knowledge of the type of proximal and distal muscle activity used during handwriting can help occupational therapists plan treatment for children with handwriting disabilities.

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Writing is an essential activity for children in school and at home. Elementary school children often spend up to 50% of their school day involved in handwriting tasks (McHale & Cermak, 1992). Learning to write legibly and efficiently allows a child to accomplish high-level academic activities and to convey important information to parents, teachers, and peers (Weil & Amundson, 1996).

Studies have found that between 10% and 20% of children in elementary school have handwriting problems (Alston & Taylor, 1987; Salvesen & Undheim, 1994; Svensson, Lundberg, & Jacobson, 2001). In fact, one common reason for referring a school-age child to occupational therapy is a handwriting problem (Oliver, 1990). Because writing is a complex skill, a handwriting problem can result from several factors, including limited cognitive, visual–perceptual, and fine-motor skills (Maeland, 1992; Tseng & Chow, 2000).

When treating children with handwriting problems, occupational therapists often address their motor skills. They strengthen clients' muscles both in the shoulder girdle and in the distal muscles of the hand. A stable base of support and fluid motion in the proximal upper extremity appear to be necessary for distal control and proficient hand skills (Benbow, 1995).

The proximal–distal principle, which states that proximal stability is a prerequisite for manipulative hand use, is widely accepted among occupational and physical therapists (Tudor, 1981). However, studies investigating this principle have

been unable to support the hypothesis that the development of distal control is dependent on proximal motor development. In fact, it appears that these two systems work separately and independently of each other, exhibiting different types of control (Kuypers, 1963; Lawrence & Kuypers, 1965; Loria, 1980). Nevertheless, it is impossible for therapists working with children to address hand function without observing that the hand is dependent on the forearm and, in turn, the shoulder girdle to position it properly in space and provide support and direction for its fine movements (Ayres, 1974). This “functional relationship” between proximal and distal motor functions, as Ayres described it, was supported by a study by Case-Smith, Fisher, and Bauer (1989) that found a significant but weak relationship between proximal motor control and distal motor skill in normal infants.

A study by Cornhill and Case-Smith (1996) indicated that there is a strong relationship between in-hand manipulation (which requires intrinsic distal muscle action for precise control of thumb and fingers) and proficiency in handwriting. Occupational therapists often address both proximal and distal components influencing handwriting, but a review of the literature did not reveal any studies that examined the relationship between proximal and distal muscle control and the functional task of writing.

One method of measuring muscle activity is through physiological analysis of gross muscle activity, such as surface electromyography (EMG). In EMG, the amount of electrical activity in the muscle being analyzed is demonstrated by the amplitude of the EMG in microvolts. Surface EMG has been used in several studies to measure the activity of specific muscles used during functional tasks (Hirashima, Kadota, Sakurai, Kudo, & Ohtsuki, 2002; Illyes & Kiss, 2003; Spaulding & Robinson, 1984).

One can learn about the type of muscle activity exhibited by analyzing the variability in the amplitude of the EMG (Nussbaum, 2001; Peper & Carson, 1999). It appears that muscles that work primarily as stabilizers display less variability than muscles that work dynamically (Peper & Carson, 1999). In addition, a large amount of variability in muscle activity seems to indicate the use of unnecessary movements that require a greater expenditure of energy. It has been found that practicing a task allows it to be performed smoothly and efficiently, with less energy expenditure, and is associated with a decrease in unnecessary muscle contractions (Lay, Sparrow, Hughes, & O'Dwyer, 2002).

Shambes (1976) used EMG to measure eight proximal muscles in 4- and 8-year-old children performing six developmental postural tasks. The study found that the older children demonstrated smaller degrees of muscle activity and

had muscles that were continuously active, as opposed to the greater and more sporadic bursts of activity in the proximal muscles of the younger children. Thus, more mature and stable movement patterns were associated with less variability in muscle activity, whereas less mature and stable movement patterns were associated with greater variability.

Wilson and Trombly (1984) used EMG to examine proximal muscle activity in the shoulder in typically developing children and in children with sensory integrative dysfunction while the children performed tasks requiring distal control. They found that children with sensory integrative dysfunction demonstrated significantly greater proximal muscle activity than the typically developing children, suggesting that the former exhibited deficient use of proximal muscles for tonic stabilization and therefore fixated the joints using stronger phasic contractions. No significant correlation, however, was found between the extent of proximal muscle activity and degree of skill in distal motor tasks.

In the present study, we describe what occurs in proximal and distal muscles of the upper extremity in typically developing children without handwriting problems during a handwriting task. We addressed three questions:

1. Do proximal shoulder muscles demonstrate different electrical activity from distal muscles during handwriting tasks?
2. What is the relationship between proximal and distal muscle activity during handwriting?
3. Is the activity of proximal and distal muscles associated with the quality and speed of a child's handwriting?

We hypothesized that the proximal muscles that, during a handwriting task, are assumed to function as stabilizers would work at a constant level of activity and display less variability in electrical activity as measured by EMG, whereas the distal muscles, whose activity is assumed to be more dynamic, would exhibit greater variability in muscle activity. We speculated that increased efficiency in muscle activity would be associated with less variability. In addition, we hypothesized that enhanced efficiency in muscle activity (i.e., less variability) would be associated with a more optimal product in handwriting.

Method

Participants

The participants in this study were a convenience sample of 35 third- and fourth-grade children in an Israeli public school who had mastered writing skills. They were not receiving occupational therapy treatment, nor were they identified as having a handwriting impairment on the basis of results on the Aleph–Aleph Ktav Yad (AAKY) Handwriting

Test (Aruz & Parush, 1999). The children's mean age was 9.7 years (range 8.5–10.5); 62% were girls, and 92% demonstrated right hand dominance. We obtained consent to participate in the study from the Board of Education, the school, the parents, and each child.

Instruments

We used the AAKY test to measure speed and quality of handwriting. Occupational therapists use the AAKY extensively in Israel to test Hebrew script handwriting. It measures writing components similar to those measured in commonly used English handwriting assessments (e.g., Evaluation Tool of Children's Handwriting; Amundson, 1995). The AAKY has been found to be reliable and valid in distinguishing children with and without handwriting problems (Lipshitz & Parush, 1993) and reflects a developmental sequence of writing. Internal reliability ($\alpha = .81$) was found for all parts of the test (Aruz & Parush, 1999). Handwriting speed is measured by counting the number of letters written in 1 min and the amount of time taken to write a 106-letter paragraph. Legibility is measured by determining the number of unidentifiable letters that make it more difficult to read the paragraph accurately and by looking at spatial organization on the paper, which includes spacing, sizing, attention to margins, and alignment on writing guidelines. Each criterion for spatial organization is scored on a scale of 1 to 4 (1 = *best*, 4 = *worst*).

We compared the participants' results to means and cutoff scores obtained for normal populations of third-grade children in Israel. A child was determined to have a handwriting impairment when he or she obtained scores lower than the cutoff scores in at least two areas (number of letters per minute, time to write the paragraph, number of illegible letters, number of corrections, spatial organization). We identified 5 of the 40 children tested as having a handwriting impairment and eliminated them from the study.

We used surface EMG (ProComp 2 with BioGraph; Thought Technology, n.d.) to assess muscle activity in the upper trapezius and the thumb muscles. The purpose of the study was to determine whether there was a connection between proximal and distal muscle activity in the upper extremity; therefore, we investigated one muscle of each muscle type. We chose muscles on the basis of previous studies of upper-extremity muscle function (Benbow, 1997; Engin, 1980; Ince, Leon, & Christidis, 1986; Shambes, 1976; Wilson & Trombly, 1984) and included the intrinsic muscles of the thenar eminence (abductor pollicis brevis, flexor pollicis brevis, opponens pollicis) and one proximal shoulder muscle: upper fibers of the trapezius. The rationale for selecting the thenar muscles was that these are considered the "skill triad" of the hand and are believed to have a primary role in writ-

ing (Benbow, 1997). The rationale for selecting the upper trapezius was that it is a superficial shoulder muscle that is appropriate to measure with surface electrodes. In addition, it is thought that shoulder elevation may be a compensation children use when having difficulty during a handwriting task (Blangsted, Hansen, & Jensen, 2003).

Bipolar surface electrodes ($\frac{2}{3}$ cm \times 3 cm) were placed with a 1 cm interelectrode distance over the upper trapezius and thenar muscles. Electrodes for the upper trapezius were placed midway on the horizontal line between the root of the spine of the scapula and the thoracic spine, and a reference electrode was placed over the clavicle. The electrodes for the thenar area were placed on the center of the thenar belly, and a reference electrode was placed over the radial styloid. The sampling rate was 32 samples per second.

Raw data were transferred to the Excel program and analyzed using SPSS Version 11.5. All raw values were standardized to baseline raw data to eliminate environmental disturbances. An electronic trigger connected to one of the EMG channels was used to signal a word at the beginning and at the end of the AAKY paragraph, for which activity in each muscle being tested was later analyzed. These words were selected because we were interested in analyzing a brief component that would represent the functional activity of writing without being obscured by other factors (e.g., spacing or breaks between words, attention and concentration of the child during the entire paragraph). Each of the words selected contained four letters, and the same words were analyzed for all the participants.

Procedure

Each child was accompanied into a room equipped with a height-adjustable desk and chair. The test administrator adjusted the seating for each child so that the child was sitting with feet resting on the floor and hips and knees at 90 degrees, and the desk surface was adjusted to 5 cm above the child's bent forearm. The administrator briefly explained the procedure to each child and asked the child to fill out a demographic questionnaire. The administrator prepared the child's skin with alcohol to reduce skin impedance and placed the electrodes on the muscles being tested. The child was given a few minutes to practice writing while attached to the EMG recorder. Baseline measurements were obtained by asking the child to sit still for 15 s with arms resting on the desk. The administrator then gave the child verbal instructions to begin copying the paragraph and instructed the child when to stop.

Data Analysis

We calculated means and standard deviations to describe the speed and quality of writing. For each word for which

an EMG was recorded, there was an average of 106 values (mV) that represented the amplitude of the working muscle unit at that point in time. We calculated the coefficient of variation (CV; standard deviation ÷ mean) of the muscle amplitude for each word in each muscle for each child. We used the Wilcoxon signed-rank test to test the assumption that the variability in muscle activity was different between proximal and distal muscles during writing and the Pearson's correlation coefficient to test the relationships between muscle activity patterns and between muscle activity patterns and writing performance. All analyses were carried out using SPSS Version 11.5 for Windows. Results were considered statistically significant when $p < .05$.

Results

The children in this study wrote a mean of 49.7 letters per minute (2 *SD* above the mean Israeli norm value of 43 letters for their age), and it took them an average of 2.2 min to write the 106-letter paragraph (norm mean = 3.0). In addition, they wrote a mean of 9.3 unidentifiable letters (3 *SD* above the mean Israeli norm value of 4 for their age) and scored an average of 7.3 in spatial organization (norm mean = 8). In other words, the children in the study wrote faster but displayed poorer quality of writing than the norms.

There were significantly greater amounts of muscle activity in the distal muscles than in the proximal muscle in both the first and second word. The mean amplitude of the thumb muscles was 25.8 in the first word and 27.3 in the second word, and the mean amplitude of the trapezius muscle was 1.4 in the first word and 2.5 in the second word.

To test the assumption that the proximal muscle works as a stabilizer and would therefore demonstrate less variability compared with the distal muscles, which work dynamically during a writing task, we compared CV values between muscles for both words (Table 1). In both words, the distal muscles' CV values were significantly higher than those of the proximal muscle, displaying greater variability. No significant differences were found within each muscle, proximal or distal, between words.

In response to the second study question—What is the relationship between proximal and distal muscle activity

Table 1. Coefficient of Variation (CV) Values in Proximal and Distal Muscles in the First and Second Word

	Mean (<i>SD</i>) Distal Muscle CV	Mean (<i>SD</i>) Proximal Muscle CV	p^a
First word	0.32 (0.18)	0.27 (0.11)	0.7
Second word	0.36 (0.16)	0.30 (0.15)	0.4
p	.37	.30	

Note. Proximal = trapezius muscle; distal = thumb muscles.

^aWilcoxon signed-rank test.

Table 2. Correlations Between Muscle Coefficient of Variation (CV) Values and Handwriting Components

Muscle	Letters per Minute	Total Paragraph Time	Spatial Organization	Unidentifiable Letters
Distal (CV1)	-0.40*	0.31*	0.24	0.21
Proximal (CV1)	0.23	0.20	0.16	0.23
Distal (CV2)	-0.34*	0.34*	0.22	0.17
Proximal (CV2)	0.22	0.18	0.11	0.13

Note. Proximal = trapezius muscle; distal = thumb muscles. Values are Pearson correlation coefficients.

* $p < .05$.

during handwriting?—we found a moderately significant positive correlation between proximal and distal muscle CV values in both the first ($r = .55, p < .01$) and second ($r = .68, p < .01$) words. In other words, when the proximal muscle displayed relatively low variability, the distal muscles displayed relatively low variability as well, and when the proximal muscle exhibited relatively greater variability, the distal muscles exhibited relatively greater variability as well.

In response to the third study question—Is the activity of proximal and distal muscles associated with the quality and speed of a child's handwriting?—we found significant but weak correlations between distal muscle variability and writing speed (Table 2). In other words, less variability in the distal muscles was associated with faster speed of writing, or less time to write the paragraph and more letters per minute. We found no significant correlation between quality of handwriting and distal muscle activity or between proximal muscle activity and speed or quality of writing.

Discussion

This study investigated muscle activity in proximal and distal muscles in typically developing children during a handwriting task. We found significant differences between muscle activity in the shoulder and in the thumb, with significantly less variability in the shoulder muscle. In addition, we found that increased variability in muscle activity in the shoulder was associated with increased variability in muscle activity in the thumb and vice versa. Finally, decreased variability in the thumb muscles was significantly associated with better speed of writing. There were no significant relationships between muscle activity and quality of writing.

Research has found that motor tasks in general, and writing or drawing in particular, operate under different work constraints. One constraint is the goal of performing to generate an optimal product (Latash & Anson, 1996). Writing is a complex task, and it is therefore difficult to determine its optimal product. Which component—speed, quality, or a combination of the two—is of greater importance? Another

concept under which the motor system operates is the principle of conservation: The system attempts to perform a task in the most economical way within the framework of the resources available.

In the present study, we assumed that the most economical muscle activity would involve a relatively low amount of variability in both the proximal and the distal muscles. In general, we found that there was less variability in the proximal than in the distal muscles. This finding might be related to the fact that the proximal muscle is used in writing primarily for stabilizing purposes and may require minimal muscle activation. It appears that tonic or isometric contractions require minimal muscle activation and display less variability than muscles that work dynamically (Peper & Carson, 1999). It might therefore be assumed that the proximal shoulder muscle uses tonic, as opposed to phasic, contractions during a writing task. These two systems have been found to function differently; phasic motor units involve a greater use of energy (Tokizane & Shimazu, 1964). This finding received support from Wilson and Trombly (1984), who found that children such as those with sensory integrative dysfunction, who are unable to use proximal muscles efficiently for stabilization, may use stronger phasic muscle contractions to compensate.

In addition, we found that relatively less variability in the proximal muscle was associated with relatively less variability in the distal muscles (i.e., more efficient and economical activity). Conversely, greater variability in the proximal muscle was associated with greater variability in the distal muscles (i.e., less efficient and economical activity). This finding seems to indicate that when the proximal shoulder muscle is used primarily for tonic stabilization, the dynamic work of the distal muscles also is more efficient, and less energy is used.

This image is expanded when one considers the connection to the product: speed and quality of writing. We found that the more economical distal muscle activity was related to greater efficiency in writing speed. In the kinetic aspect, it appears that children who are less efficient writers can be characterized as exhibiting a greater physical expenditure in performance. Studies investigating neuromotor variability during writing in children with and without writing disabilities have described this relationship in depth (Smits-Engelsman, Niemeijer, & Van Galen, 2001; Van Galen, Portier, Smits-Engelsman, & Schomaker; 1993).

Van Galen et al. (1993) used a digitizer and electronic pencil to record writing movements and examined biomechanical differences between second- to fourth-grade children characterized as poor and competent writers. The study found that less proficient writers displayed higher movement velocities and greater amounts of undesirable

movements, exhibited as neuromotor noise. The more proficient writers exhibited less noisy movement profiles. The authors suggested that poor writers demonstrated a suboptimal motor system and were unable to keep the variability of movement within normal limits. These findings are consistent with the results of our study, which found a positive correlation between decreased variability in distal muscles and better writing speed. Children who write less efficiently (as evidenced in our study by slower writing speed) may display a greater amount of variability in muscle activity and are unable to inhibit undesirable movements (i.e., noise). According to Van Galen et al., the poorer writers were unable to use appropriate biomechanical strategies to inhibit noise, resulting in a cruder movement style. Increased variability in both kinematic components and in muscle activity may indicate the use of undesirable movements that are unnecessary for the final product. Greater energy use is therefore required, which may bring about a less optimal product in terms of either quality or writing speed.

In the present study, more efficient distal muscle activity was significantly associated only with better speed and not with quality of writing. There are several possible explanations for this observation. First, it is possible that, by definition, speed components are quantitative measures, whereas the quality components—illegible letters and spatial organization on the paper—are qualitative but made into quantitative measures for the purposes of the assessment. The AAKY handwriting test is an accepted, valid, and reliable assessment used extensively in Israel to identify children with handwriting disabilities, but because its main purpose is to identify children with disabilities, it may be less reliable and less sensitive in grading writing quality in children without disabilities. Possible evidence for this assumption is the large standard deviation we found for illegible letters in the study children compared with the norms as opposed to the smaller standard deviation for speed.

Another possible explanation for the association of efficiency in distal muscle activity only with better writing speed, and not with quality of writing, is related to the attempt to deliver an optimal outcome. The product of a writing task is made up of several components, and an emphasis on quality as the optimal component is liable to bring about a neglect of speed, whereas an emphasis on speed may compromise quality. The large variability in quality of writing both between children and within each child under different circumstances has been previously described; this variability can be attributed to different factors that are connected to writing, including objective difficulties, such as an attention disability, motor difficulties and eye–hand coordination difficulties, or the child's motivation (Graham, Struck, Santoro, & Berninger, 2006; Maeland,

1992; Smits-Engelsman et al., 2001). The fact that in this study the mean group scores for writing quality were significantly poorer than the norms, whereas the mean group scores for writing speed were significantly better than the norms, supports the assumption that the children viewed this task as a task of speed and therefore attempted to obtain the optimal speed, thus neglecting quality.

We also speculate that because the norms for the AAKY test were originally established in 1999, the writing techniques of Israeli children have changed somewhat because of the much more frequent use of the computer as a writing tool. This change in writing habits may have strengthened writing speed while compromising writing quality; it appears that writing using a keyboard decreases handwriting practice and requires different skills from handwriting (Preminger, Weiss, & Weintraub, 2004).

Limitations of the Study

The study sample was small and was taken from just one school, thus limiting the ability to generalize the results to a larger population. In addition, positioning of the EMG electrodes may have interfered with grasp, thus reducing quality of writing. We attempted to compensate for this possible interference by giving the children time to experiment with writing while attached to the electrodes before starting the actual test. In addition, when questioned, the children denied that the electrodes caused any discomfort.

Finally, because of practical considerations, this study examined only one proximal muscle, but several other muscles contribute to activity and stability in the shoulder. An analysis of other muscles, both separately and combined, may shed more light on what actually occurs in the shoulder during writing.

Conclusion

This is the first study, to the authors' knowledge, that examined muscle output in proximal and distal muscles during handwriting using EMG. We found an association between proximal and distal muscle activity variability and discovered that decreased variability in distal muscles was related to better efficiency in writing. Although we assumed that decreased variability in proximal muscles might be related to greater stability, the study could not prove that lack of ability in fine-motor function is related to lack of stability in proximal muscles (Ayres, 1974). Further studies should examine other proximal shoulder muscles and investigate more specific relationships between stability in shoulder muscles and distal control in writing.

The results of this study appear to be supported by studies exploring kinematic aspects of writing. Further studies should investigate handwriting movements using both EMG and devices measuring kinematic components to determine how these two aspects relate.

This study examined typically developing children. Further studies are needed with children diagnosed with handwriting impairments. Knowledge of differences in muscle activity in this population during handwriting tasks can help occupational therapists plan appropriate treatments for specific handwriting problems.

The results of this study appear to support occupational therapists' observations in the clinic that a stable base of support in the proximal upper extremity is necessary for efficient distal control during writing. When therapists treat children with handwriting problems, it may be important to address both stability in the proximal shoulder muscles and efficiency in the distal hand or thumb muscles simultaneously. Weight-bearing and compression-type activities can be used to provide stability in the shoulder joint, and manipulative activities done on a vertical surface or thumb-resistive activities can allow for more efficient control in the thumb (Benbow, 1995).

In addition, occupational therapists should consider using EMG both as an evaluation tool and as a method of treatment for handwriting problems. EMG can be used as an evaluation tool to determine the type of proximal and distal muscle activity exhibited by the children whom they are treating. EMG can add more information to existing evaluation tools and possibly support occupational therapists' clinical observations in practice. In addition, EMG biofeedback should be explored as a treatment of choice for training children with handwriting disabilities to use the muscles necessary for handwriting in an efficient manner. ▲

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