Temporal measures of poor and proficient handwriters

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Abstract

The objective of this study was to use quantitative outcome measures of children’s handwriting to examine differences in the temporal characteristics of proficient and poor handwriters. This was accomplished by using an x-y digitizer to sample the handwriting of 100 third grade children as they performed a series of functional tasks of varying length and complexity. A major finding was that the poor handwriters performed significantly worse on all of the tested temporal variables than did their peers. Moreover, all the children, and especially the poor handwriters, did not maintain contact with the writing surface for large percentages of the total writing time. The educational implications of these results are discussed.

1. Introduction

Handwriting is a complex human activity that involves sequences of rapid, alternating, time-constrained motions (Keele, 1987; Semjen, 1992; Wing, 1978). It is characterized by an intricate blend of sensory-motor, perceptual, and cognitive components that interact closely as a child matures, develops, and learns new skills (Bonny, 1992; Smits-Engelsman & Van Galen, 1997). During their first three years of school, children are expected to acquire a level of handwriting proficiency that will enable them to make skillful use of writing as a “tool” to carry out their “work” at school. For most children, writing becomes an automatic tool that enables them to organize their thoughts, and express the knowledge they acquire during their formative years (Phelps, Stempel & Speck, 1985).

Elementary school children typically spend up to 50% of the school day engaged in writing tasks, some of which are performed under constraints of time (Amundson & Weil, 1996; McHale and Cermak, 1992; Tseng & Chow, 2000). Thus, a child’s ability to write legibly, as well as quickly and efficiently, enables him or her to achieve both functional written communication and academic advancement (Amundson & Weil, 1996; Phelps et al., 1985; Tseng & Cermak, 1993; Tseng & Hsueh, 1997). It has been suggested that writing difficulties may have serious consequences for the student’s academic progress, emotional well-being and social functioning (Cornhill & Case-Smith, 1996; Kaminsky & Powers, 1981; Modlinger, 1983). Smits-Engelsman et al., (1995) reported that 32% of the boys and 11% of the girls in The Netherlands were described by their teachers as having significant handwriting difficulties. These numbers are similar to the findings of Rubin & Henderson (1982) who estimated that 12 to 21 percent of elementary students in England displayed problems related to writing legibility or speed.

Despite the considerable consequences that poor handwriting appears to have on the child’s academic performance and emotional well-being, relative to the wealth of data investigating reading difficulties, very little research on the nature and cause of writing difficulties is available (Amundson & Weil, 1996; Berninger, Mizokawa, & Bragg, 1991; Cermak, 1991; Rubin & Henderson, 1982; Tseng & Chow, 2000).

Developments in data collection technology now permit the examination of set of handwriting outcome measures. With the aid of a digitizing tablet and instrumented pen a child’s handwriting can be monitored in
real-time and stored in a format amenable to sophisticated kinematic and kinetic analyses (e.g., Tseng & Chow, 2000, Smits-Engelsman & Van Galen, 1997). The use of such devices enables the measurement of not only the simpler temporal variables that were measured in previous studies; they also enable the researcher to achieve greater precision or detail in the temporal dimension (e.g., the amount of time that a child holds his pen above the writing surface, on the writing surface, or the ratio between the two) that can reveal further important information about the child’s handwriting. Due to the portability of the digitizing tablet and a laptop computer, all these measures can be obtained in the child’s natural classroom environment. Finally, due to automation of the data collection and analysis procedures, it is feasible to collect relatively large numbers of handwriting samples in a single experimental session. Thus, a variety of graded tasks such as having the child write very brief texts (a single letter or word), or longer texts (a single sentence or paragraph), copying from a visual stimulus or writing in response to a dictated phrase, can be obtained. This abundance of data provides the possibility of examining effects such as changes in a child’s handwriting as a function of fatigue, task complexity, or text presentation modality.

The objective of this study was to use quantitative outcome measures of children’s handwriting to examine differences in the temporal characteristics of proficient and poor handwriters. This was accomplished by on-line sampling the handwriting of 100 third grade children as they performed a series of functional tasks that varied in terms of task type (shapes versus letters), task length (single letters versus words versus phrases and sentences), and task stimulus (visual versus auditory stimuli). This presentation focuses on temporal analyses of copying handwriting tasks of varying length and complexity.

2. Methods
2.1 Subjects
Two groups (proficient and poor handwriters) each with 50 third grade pupils, aged 8 and 9 years old, were recruited from eight regular public schools located in four different types of municipalities in northern Israel (large town, small town, kibbutz and community settlement). All subjects were born in Israel, used the Hebrew language as their primary means of verbal and written communication, and were right hand dominant. The 100 children who were selected to participate in this study were identified as proficient or poor handwriters with the aid of a handwriting skill questionnaire filled in by classroom teachers. Children with documented developmental delay, neurological deficits, or physical impairment were excluded from the study.

The proficient handwriters were matched to the subjects in the poor handwriting group on the basis of gender, age, school, and class. There were no significant differences between the two groups with respect to their age (8.68 ± 0.27 years for the proficient handwriters and 8.61 ± 0.35 years for the poor handwriters) and gender ratio (30% girls versus 70% boys in both groups).

2.2 Instruments
A suite of on-line, computerized tasks developed via Matlab software toolkits was used to administer the stimuli and to collect and analyze the data. All writing tasks were performed on A4 size lined paper affixed to the surface of a WACOM (407 X 417 X 36.3 mm) x-y digitizing tablet using a wireless electronic pen with pressure sensitive tip (model Up 401). Pen size and weight were similar to those of normal pens (length=150mm, circumference=35mm, weight=11gm). The paper was lined (spacing=0.5 cm). Displacement, pressure, and pen tip angle were sampled at 150 Hz via a 90 MHz Pentium laptop computer.

2.3 Handwriting Tasks
The suite of tasks included 51 items which were graded in type and complexity, ranging from shapes, to single letters, to words, sentences and paragraphs. Some of the tasks were presented visually on the screen (copying tasks) and others via an auditory stimulus (recorded voice, dictated tasks). In the case of visual stimuli, the task was displayed in Hebrew font type Gutman Yad-Brush size 20 point. Most items were selected to represent handwriting tasks in which a child would typically engage. The tasks analyzed in this paper included copying seven different single letters from the computer screen, copying four different words, writing two 22 character long sentences (one familiar and one unknown), and copying a 100 character long paragraph.

2.4 Outcome Measures
The primary outcome measures included the total time to complete each task, “in air” time (i.e. the total time during the task that the pen was not in contact with the writing surface) and mean writing speed. The mean “in air” time as a percent of total time was derived from these primary measures.

2.5 Procedure
All subjects performed the experiment under similar environmental conditions in a quiet classroom in their school. Each subject was tested individually during the morning hours. The subject was seated on a standard school chair and in front of
a school desk, which were appropriate to his or her height. The tasks were drawn or written on normal writing paper with printed lineature, which was affixed to the digitizing tablet.

3. Results
To test for the group differences (poor versus proficient handwriters) across tasks (single letters, words, sentences and paragraphs) for each dependent variable (e.g., total time, “in air” time) the data were subjected to MANOVAs. The first temporal variable to be examined in detail is the mean total time taken by proficient and by poor handwriters to complete copying tasks of different lengths (see Table 1). As expected, the mean total time increased as a function of task length (i.e., from 1 to 4 to 22 and to 100 characters).

Table 1: Mean total writing time.

<table>
<thead>
<tr>
<th>Task</th>
<th>Mean number of letters per task</th>
<th>Proficient (Mean ± SD)</th>
<th>Poor (Mean ± SD)</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Letter</td>
<td>1</td>
<td>1.27 ± 0.46</td>
<td>1.62 ± 0.84</td>
<td>*</td>
</tr>
<tr>
<td>Word</td>
<td>3.75</td>
<td>3.3 ± 0.92</td>
<td>5.64 ± 2.16</td>
<td>**</td>
</tr>
<tr>
<td>Sentence</td>
<td>22</td>
<td>23.37 ± 7.06</td>
<td>46.66 ± 22.80</td>
<td>**</td>
</tr>
<tr>
<td>Paragraph</td>
<td>100</td>
<td>171.29 ± 55.85</td>
<td>313.12 ± 131.07</td>
<td>**</td>
</tr>
</tbody>
</table>

The MANOVA applied to mean total time yielded a significant result (F(4,91)=14.63, p<.0001). To examine the source of the significance the data from each task were subjected to univariate ANOVAs. The results showed that proficient handwriters took significantly less time to complete the writing tasks than did the poor handwriters.

One of the major advantages of using an x-y digitizer is the ability to record “in air” time, that is the total time throughout a given task that the pen is not in contact with the paper. The MANOVA for this variable yielded significant differences (F(5,90)=12.68, p<.0001) between the two groups. As was the case for mean total time, mean “in air” time increased as a function of task length for both the poor and proficient handwriters (shown in Table 2).

Table 2: Mean “in air” time.

<table>
<thead>
<tr>
<th>Task</th>
<th>Mean number of letters per task</th>
<th>Proficient (Mean ± SD)</th>
<th>Poor (Mean ± SD)</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Letter</td>
<td>1</td>
<td>0.16 ± 0.14</td>
<td>0.30 ± 0.41</td>
<td>*</td>
</tr>
<tr>
<td>Word</td>
<td>3.75</td>
<td>1.41 ± 0.53</td>
<td>2.87 ± 1.49</td>
<td>**</td>
</tr>
<tr>
<td>Sentence</td>
<td>22</td>
<td>14.93 ± 5.83</td>
<td>34.14 ± 20.06</td>
<td>**</td>
</tr>
<tr>
<td>Paragraph</td>
<td>100</td>
<td>123.78 ± 47.79</td>
<td>246.17 ± 117.79</td>
<td>**</td>
</tr>
</tbody>
</table>

In order to determine whether “in air” time increased strictly as a function of task length or due to one or more other factors, “in air” time as a percent of total writing time was also examined (shown in Table 3). The MANOVA for this variable yielded significant differences (F(4,91)=5.12, p<.0009) between the two groups. There were significant differences in the univariate ANOVA analyses only for the sentence and paragraph tasks.

Table 3: Mean “in air” time as a percent of total time.

<table>
<thead>
<tr>
<th>Task</th>
<th>Mean number of letters per task</th>
<th>Proficient (Mean ± SD)</th>
<th>Poor (Mean ± SD)</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Letter</td>
<td>1</td>
<td>12.41 ± 8.27</td>
<td>15.48 ± 12.64</td>
<td></td>
</tr>
<tr>
<td>Word</td>
<td>3.75</td>
<td>42.46 ± 9.84</td>
<td>49.25 ± 11.23</td>
<td></td>
</tr>
<tr>
<td>Sentence</td>
<td>22</td>
<td>62.73 ± 7.42</td>
<td>70.32 ± 9.29</td>
<td>**</td>
</tr>
<tr>
<td>Paragraph</td>
<td>100</td>
<td>71.07 ± 5.82</td>
<td>76.88 ± 7.49</td>
<td>**</td>
</tr>
</tbody>
</table>
Although there continued to be an increase in “in air” time as task length increased for both poor and proficient handwriters, the differences of “in air” time as a percentage of total time were much smaller. For example, whereas poor handwriters spent more than seven times as much time “in air” when copying a 100 character paragraph as compared to when they copied a 22 character sentence (Table 2, column 4, 246.17s versus 34.14s), there was only a difference of 7.5% when percents for the same tasks are compared (Table 3, column 4, 76.9% versus 70.3%).

The most important result of the data shown in Table 3 is the fact that both poor and proficient handwriters spent such a large percentage of time “in air”, especially for the longer tasks. For example, proficient handwriters spent about 71% of the total writing time “in air” when copying a 100-character paragraph. Poor handwriters spent about 77% of the total writing time “in air” at the same task.

Table 4 highlights differences between proficient and poor handwriters in the time they needed to complete longer handwriting tasks in a manner commonly used in educational settings. The data in this table show the number of characters per minute calculated by dividing the total number of characters in a 100-character paragraph by the total time it took subjects to complete that task. The differences between the two groups were highly significant (F(8,90) p<.0001).

<table>
<thead>
<tr>
<th>Task</th>
<th>Number of characters</th>
<th>Proficient (Mean± SD)</th>
<th>Poor (Mean± SD)</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paragraph</td>
<td>100</td>
<td>41.12 ± 13.26</td>
<td>24.28 ± 10.54</td>
<td>**</td>
</tr>
</tbody>
</table>

4. Discussion
In the current study handwriting samples of progressively increasing complexity were recorded in real time via an x-y digitizer with the aim of comparing the temporal characteristics of poor handwriters relative to matched control children. The major finding was that the poor handwriters performed significantly worse on all of the tested temporal variables than did their peers. For most variables these differences were already apparent when the subjects engaged in the simpler tasks (single characters and words). Thus, mean total time was found to be significantly different between the two groups at all levels of complexity. Moreover, there were significant differences between the two groups for the number of characters per minute.

The finding that temporal variables differentiate between proficient and poor handwriters is supported by results from studies that used traditional handwriting evaluation scales to measure writing speed. These usually focused on the measurement of writing speed measured as the time taken to complete a given (standardized) writing passage or how much can be written in a set period of time (Erez, Yochman, & Parush, 1996; Hamstra-Bletz & Blote, 1993; Rubin & Henderson, 1982).

In contrast, in one of the first uses of a digitizer to examine differences between proficient and poor handwriting, Wann & Jones (1986) did not find mean total time to be a good differentiator between two groups of Grade 4 and 5 children. However, when the data from only the Grade 4 children were examined, the results were similar to our findings. Sovik, Arntzen, & Thygesen (1987) found no differences in mean writing speed between three groups of 3rd grade children, comparing typical, dysgraphic and dyslexic children. Sovik, Maeland & Karlsdottir (1989) also found in their study of typical and dysgraphic nine year old children that they did not differ with respect to writing speed.

Pauses, or temporary halts in the flow of writing, are another temporal variable that has been studied over the years. For example, numerous clinical observations have reported on the tendency of poor handwriters to pause frequently while writing (Benow,1995; Kaminsky & Powers,1981). Due to a lack of a methodology for quantifying their observations, such studies do not provide any detail about what occurs when the handwriter pauses. They are therefore unable to further our understanding of why children pause, and whether pauses serve as an aid or a hindrance to the writing process. Does the child merely rest his pen on the paper until he was ready to continue writing, or does he continue to maneuver the pen, albeit not on the writing surface? Indeed, what has classically been referred to as a pause in handwriting may consist of sequelae of pauses and other manipulations of the pen that do not result in any impression on the writing surface.

Data sampled via an x-y digitizer does permit a more detailed examination of handwriting pauses, although few studies have fully exploited this ability. Sovik, Arntzen, & Thygesen (1987) found that proficient handwriters paused for less time than poor handwriters while writing single words. Wann & Jones (1986) found that poor writers paused more frequently and for longer periods in comparison with proficient handwriters, and suggested that this phenomenon, rather than total time, is a good indicator of writing difficulties.
In the current study an important segment of the pause, namely “in air” time (the total time throughout a given task that the pen is not in contact with the paper) has been examined in detail. Our results demonstrated that both proficient and poor handwriters did not maintain contact with the writing surface for large percentages of the total writing time; this reached as much as two thirds of the total time when writing a 100 character paragraph. Furthermore, the poor handwriters maintained even less contact with the writing surface than did the proficient handwriters when writing sentences and paragraphs.

Examination of numerous “in air” samples led us to describe the “in air” phenomenon as a “motion tour” taking place in the air between the writing of successive characters segments, letters and words. It is anticipated that further in-depth analyses of the spatial variables will lead to a greater understanding of the phenomenon.

How can we account for the fact that children appear to spend so much time “not writing” while writing? One possible explanation may be the age of our subjects, and the relative immaturity of their handwriting, although children of this age are usually considered to be mature handwriters (Levine, 1987). While many children of this age have likely achieved a mature level of handwriting, it may be that a significant number do not do so before Grades 4 or 5. It would appear to be worthwhile to examine the handwriting of children somewhat older than the sample examined in this study in order to determine the effect of age, and handwriting maturity on “in air” time.

It has been suggested that handwriting is not “mechanical” or “automatic” for many young writers (Berninger, Vaughan, Abbott, Woodruff-Rogan, & Brooks & Rogan, 1997; Oliver, 1990; Cermak, 1991; Amundson & Weil, 1996), and it may be that the “in air” time helps them to prepare to execute subsequent characters or character segments. This hypothesis could be tested by examining the extent of “in air” time when children are asked to perform familiar and repetitve tasks composed of basic elements that would be expected to be performed more automatically. Another explanation that cannot be overlooked is the fact that one of the main features of the Hebrew language is that successive letters are not connected. Although there is no evidence to suggest that disconnected writing leads to greater “in air” time, it may be that Hebrew handwriters make a larger number of pauses than do children writing in another language. However, there is no evidence to date that disconnected writing necessarily lead to “in air” travel. A detailed examination of “in air” time in handwriting in other character sets would help to resolve the issue.

It is interesting to consider the concept of “in air” time as an indicator of a lack of automatcity in view of Van Galen’s model of handwriting (Van Galen, 1991; Van Galen et al.1993). Based on neuropsychological and experimental evidence, this model proposes that there are three components in the performance of this motor task: the motor program, parameterization and regularization of the motor program, and muscular initiation in order that the task may be performed (Smits-Engelsman & Van Galen,1997). Perhaps the “in air” time detected in this study corresponds to the time needed to parameterize the motor program or to initiate activity in the muscle groups needed to execute the character.

These results support the incorporation of temporal variables into test batteries that are used for the identification and evaluation of poor handwriting. Further, temporal variables should be considered when designing and evaluating remedial handwriting interventions (Longstaff & Heath, 1997). Given the observed differences in temporal variables between proficient and poor handwriters, future research should include a systematic examination of spatial variables. We also suggest that future research should continue to focus on temporal variables to clarify whether these deficits can be generalized to other ways of writing, such as employing auditory input instead of visual input, as in writing from dictation. Finally, we encourage an examination of the same variables on a variety of languages that use other character sets such as Latin-based or Chinese.

References


