The In Air phenomenon:
Temporal and spatial correlates of the handwriting process

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Perceptual and Motor Skills, 96(3), 933-954

Abstract

From 10 to 30% of elementary school-aged children have handwriting difficulties. Examination of such difficulties is important due to the variety of academic, emotional and social consequences that they can impose. One such common problem is the tendency of children to pause while writing. Thus the objective of this study was to use a computerized digitizer system to examine the tendency of poor writers to pause while writing. Handwriting samples of varying type and length were collected from Grade 3 students, 50 of whom were proficient writers and 50 of whom were poor writers as determined by a questionnaire completed by the classroom teachers and verified by the Hebrew Handwriting Evaluation. Results indicated that the so-called pauses are not stationary breaks between the writing of successive segments because letters and words were usually associated with considerable movement of the pen above the writing surface. This In Air writing occurred with significantly greater frequency for poor writers than for the proficient writers in most handwriting tasks. The results suggest possible underlying perceptual-motor difficulties, which could be considered when planning effective handwriting interventions.

Key words: poor writers, school-aged children, digitizer, pauses

The act of writing presents difficulties for about 10-30% of elementary school-aged children (Rubin & Henderson, 1982; Smits-Engelsman, Van Galen, & Michels, 1995). Indeed, difficulty with the production of written language, or dysgraphia, is a common complaint among children and adults with learning disabilities (Johnson, 1995; Waber & Bernstein, 1994). This difficulty may be due to abnormalities of penmanship (e.g., legibility) or written language (e.g. spelling) or a combination of both these factors (O'Hare & Brown, 1989a; 1989b).

It has been suggested that writing difficulties may be of lower or higher order (Berninger, et al., 1997). Higher-order difficulties refer to problems in planning and content generation. Lower-order difficulties refer to the mechanical requirements for producing text (i.e., actually forming the letters on the writing surface) which may manifest in terms of the legibility of the written product and/or in writing speed (Graham, 1990; Graham & Weintraub, 1996). These difficulties may have serious consequences for the student's academic progress, emotional well-being and social functioning (Kaminsky & Powers, 1981; Modlinger, 1983; Cornhill & Case-Smith, 1996).

Since 30% to 60% of children's school day is spent in the performance of fine motor tasks, consisting primarily of handwriting tasks (McHale & Cermak, 1992) it is likely that the quality of their handwriting skill will affect academic performance. Several authors have suggested that difficulty in mastering of the mechanical aspects of handwriting may interfere with higher order processes required for the composition of text (Berninger & Graham, 1998). Graham (1990) found that handwriting mechanics influence the quality and quantity of the written product. This finding was supported by that of Berninger, et al. (1997), who reported that handwriting performance was significantly related to fluency and quality of composition in elementary school students. Graham, Harris, & Fink (2000) summarized views on the negative sequelae of handwriting difficulties in a recent article. They, together with others (Briggs, 1980; Hughes, Keeling & Tuck, 1983; Chase, 1986) have suggested that teachers tend to give higher marks for neatly written papers than for those in which legibility is poorer. Thus it appears that poor penmanship may influence perceptions about children's competence as writers. Other authors have proposed that handwriting among children with difficulties can interfere with the simultaneous execution of composition (Scardamialia, Bereiter, & Goleman, 1982; Graham, 1990). It may be that when letter production is not fully automatic, the act of handwriting makes increased demands on memory and attentional resources, which, in turn, constrain the higher level cognitive processes required for composition (Berninger & Graham, 1998; Jones & Christensen, 1999). Additionally, some suggest that if handwriting is very slow, children may forget the ideas and plans held in memory before they succeed in transferring them to paper (Graham & Weintraub, 1996).

Most studies that have addressed poor handwriting have focused on the written output, scrutinizing legibility according to its spatial characteristics (e.g., consistency of letter form, size and spacing) and writing speed in terms of the total time taken to complete a specific writing task (Rubin & Henderson, 1982; Ziviani & Elkins, 1984; Graham, Boyer-Schick, & Tippets, 1989; Phelps, Stempel, & Speck, 1985; Reisman,1991; 1993; Hamstra-Bletz & Blote, 1993; Erez & Parush, 1999). Sovik, Arntzen, and Thygesen (1987), and more recently Longstaff and Heath (1997), have suggested that a greater emphasis on the analysis of the writing process of dysgraphic children is necessary in order to measure their handwriting ability. The availability of technology for computerized data collection including a digitizing tablet and instrumented pen represents an important step in realizing this goal.

Children's handwriting can be monitored in real-time and stored in a format that allows sophisticated temporal and spatial analyses (Smits-Engelsman, & Van Galen, 1997; Tseng & Chow, 2000,).

Clinical observations of poor handwriters have shown that they tend to pause while writing (Kaminsky & Powers, 1981; Benbow, 1995). Pauses have been noted in the past in a number of studies based on computerized data collection (Wann & Jones, 1986; Sovik, et al., 1987; Schoemaker, et al.,1994; Schoemaker and Smits-Engelsman, 1997;Smits Engelsman, Van-Galen, & Portier, 1994a).

Sovik, et al. (1987) examined the frequency of pauses made by nine-year old proficient, dyslexic and dysgraphic handwriters while they wrote several single three and six-letter words. They found that the proficient handwriters paused for less time than the poor handwriters. Wann and Jones (1986) also observed breaks in handwriting in a study of proficient and poor handwriters in a sample of Grade 4 and 5 children. In this latter study, the writing tasks consisted of five letter units that were chosen on the basis of their assumed task difficulty (i.e., according to the number of quasi-liner, semicircular and cursive segments). They found that poor writers paused more frequently and for longer periods of time in comparison with proficient handwriters, and suggested that this phenomenon was a better indicator of writing difficulties than total writing time. Similar results were found by Smits-Engelsman et al. (1994a) who demonstrated that poor writers differed from proficient writers in the duration of the pauses that followed the completion of both upstrokes and downstrokes.

Schoemaker and Smits-Engelsman (1997) found that dysgraphic children drew more slowly and with elongated pause intervals between strokes in comparison with a control group. Schoemaker, et al. (1994) found similar results regarding clumsy children. These studies have presented children with one or two different types of tasks, such as writing words of varying lengths and drawing figures. In all cases, pauses in writing continuity were noted, with the poor handwriters making significantly longer breaks than proficient handwriters.

The theoretical basis that led these researchers to formulate their paradigms derives from motor control theory in which skilled movements are characterized by the subject's desire to perform the task efficiently in order to achieve spatial and temporal accuracy. Thus, a skilled movement appears fluent and not broken up by too frequent pauses and breaks (Sparrow, 1983; Keogh & Sugden, 1985). An additional aspect of handwriting as a skilled movement relates to the influence of contextual factors (Ellis, 1982; Wing, Nimmo-Smith, & Eldridge, 1983; Sovik, Arntzen, & Thygesen, 1986; Thomassen, Tibosch, & Maarse, 1989). For example, variations in task length (e.g., letters versus paragraphs) (Rosenblum, Parush, & Weiss, 2001), task type (letters versus writing patterns) (Mojet, 1991), task familiarity (known versus unknown writing patterns) (Smits-Engelsman, Van Galen, & Portier, 1994b), and task continuity (continuous versus discrete writing patterns) (Meulenbroek & Van Galen, 1984; Kosterman, Westzaan, & Wieringen, 1994) appear to have a great influence on skilled handwriting performance.

Pauses or breaks in writing fluency appear to have a particular importance in the evaluation of children's' handwriting difficulties. In a previous report we indicated that time and length data measured while the child's pen is above the writing surface is an important source of information about what takes place during the pause phenomenon (Rosenblum, Jessel, Adi-Japha, Parush & Weiss, 1997). Indeed, many questions arise as a result of both clinical observations of pauses, and from studies that have documented the occurrence and initial characteristics of these pauses. For example, it would be important to determine whether the pause phenomenon is age or task dependent, and to identify when it occurs within the writing sequence (e.g., between successive segments of a letter, between successive letters, between successive words in a sentence) and with what frequency. It would also be important to characterize what occurs during pauses and whether the pen is held stationary in the air or on the paper or whether it is being manipulated above the writing surface. Finally, it would be important to determine differences in the occurrence and characteristics of pauses between poor and proficient handwriters.

Examination of handwriting in non-Latin based languages such as Hebrew provides an opportunity to investigate some of the factors mentioned above. This language differs in several important ways from Latin-based scripts, as shown in Figure 1. Hebrew writing progresses from right to left, successive letters are usually not connected, even in script or cursive writing, and some letters are comprised of two separate, unconnected segments. Moreover, five of the 22 characters change shape when they terminate a word. Some of these features are illustrated in the three samples shown in the figure, showing a 4-letter Hebrew word as displayed on a computer monitor (1a), as written by an 8 year old proficient handwriter (1b) and as written by an 8 year old poor handwriter (1c).

***** Insert Figure 1 near here*****

The objective of this study was to use quantitative outcome measures of children's handwriting to examine in detail the differences in the temporal and spatial characteristics of the pauses of proficient and poor handwriters. This was accomplished by sampling the handwriting of 100 third grade children as they performed a series of tasks that varied in their contextual factors including length, type, familiarity, and continuity.

Method

Participants

Two groups of handwriters (proficient and non-proficient), each group consisting of 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 participants were born in Israel, used the Hebrew language as their primary means of verbal and written communication, and all pupils used their right hand only when handwriting. Permission to carry out this study was granted by the Ministry of Education and signed parental agreement was obtained for each participant.

Third grade pupils were selected as the target population due to the research that indicates that by the time a child reaches this grade, his or her handwriting has become automatic, organized, and readily available as a tool to facilitate the development of ideas (Levine, 1993; Berninger, Mizokawa, & Bragg, 1991). A lack of these qualities at this age may be a sign of a problem in development.

The 100 children who were selected to participate in this study were identified as proficient or non-proficient handwriters with the aid of the standardized and validated Teachers' Questionnaire for Handwriting Proficiency (Rosenblum, et al., 1997) completed by their classroom teachers. The questionnaire was constructed from criteria selected from the literature and handwriting assessments including handwriting legibility, speed, fatigue, and complaints of pain or discomfort while writing (Rubin & Henderson, 1982; Alston, 1983; Cornhill & Case-Smith, 1996). The Teacher's Questionnaire for Handwriting Proficiency was content validated through a table of specifications by ten clinicians and researchers who were occupational therapists experienced in the assessment and treatment of handwriting difficulties. The teachers were asked to use the questionnaire to evaluate the handwriting of each student with reference to the expectations of handwriting legibility and speed for children of that age and background.

Children with documented developmental delay, neurological deficits, or physical impairment were excluded from the study. After the children were classified into groups of proficient versus non-proficient handwriters according to their ratings via the Teachers' Questionnaire for Handwriting Proficiency, they were tested with the Hebrew Handwriting Evaluation (Erez & Parush, 1999), a standardized, reliable and valid handwriting assessment for the Hebrew language. The evaluation provides normative data for second and third graders. During test development, reliability and validity were established and reported in the test manual (Erez & Parush, 1999). Internal consistency was high ($\alpha = .81$), and inter-rater reliability ranged from $r = .71$ to .79. Validity was demonstrated through factor analyses and statistically significant differences on the Hebrew Handwriting Evaluation scores across subject groups (proficient and non-proficient handwriters), and across school grades (second and third) ($p < .013$ to $p < .001$). No significant differences were found for gender. One hundred percent agreement between the Teachers' Questionnaire for Handwriting Proficiency (Rosenblum, et al., 1997) and the Hebrew Handwriting Evaluation (Erez & Parush, 1999) was found. Seventy percent of these children were boys, a gender bias that has been reported in the literature for children in England (Rubin & Henderson, 1982) and the Netherlands (Smits-Engelsan, Van Galen, & Michels, 1995).

The proficient handwriters were matched to the participants in the non-proficient handwriting group on the basis of gender, age, school, and grade. For each child in the non-proficient handwriting group, a matched control participant was chosen from his or her classroom peers, and was therefore taught by the same classroom teacher. There were no statistically significant differences between the two groups with respect to age (8.7 ± 0.3 years for the proficient handwriters and 8.6 ± 0.4 years for the non-proficient handwriters) and gender ratio (30% girls versus 70% boys in both groups).

Instrument

A suite of on-line, computerized tasks developed via Matlab software toolkits were used to administer, collect and analyze participants' writing 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 90 MHz Pentium laptop computer.

Handwriting Tasks

The experimental paradigm included a suite of writing tasks which were graded in type and complexity, ranging from continuous and discrete writing patterns, to single letters, to words, sentences and paragraphs. All tasks were presented visually on a computer screen in Hebrew font Gutman Yad-Brush, in 20- point type.

The first eight tasks were 5-character writing pattern sequences. As shown in Table 1, these tasks were grouped in accordance with two key criteria. The first criterion, Continuity, related to whether the characters in the task were presented discretely or continuously. The second criterion, Language, related to whether the characters were analogous to Hebrew or English letters. For example, the two continuously formed, English-like patterns, are shown in table 1 in line (c). The two discretely formed, Hebrew-like patterns are shown in line (b).

In addition to their Continuity and Language characteristics, these writing patterns were selected because they have been used in previous studies (Maarse, Van de Veerdonk, Van der Linden, & Pranger-Moll,1991; Mojet, 1991; Kosterman, et al.,1994; Smits-Engelsman, et al., 1994a; Waber & Bernstein, 1994), facilitating a comparison of the current results to previous work. The remaining items (letters, words, sentences and paragraphs) were selected to represent handwriting tasks in which a child would typically engage.

*** Insert Table 1 near here ***

Outcome Measures

Based on preliminary analysis of the data set, the primary outcome measures included the total time to complete each task, On Paper and In Air time (i.e., the total time during the task that the pen was in contact with the paper and the time during the task that the pen was not in contact with the writing surface), the total path length, On Paper length and the In Air path length. Other variables such as the mean In Air time as a percent of total time and mean In Air length as a percent of total length were derived from these primary measures. These were analyzed automatically via customized Matlab modules.

It is important to note that our present apparatus and analytic methods did not permit us to actually measure the amount that the child's pen must be raised in order to clear the paper when moving from segment to segment, a value that may influence the In Air temporal and spatial measures. Observation of numerous subjects leads us to believe that this value is very small and, for the purposes of the present analysis, it is assumed to be zero. We are currently developing an algorithm for the identification of character segments via pattern recognition which will enable actual measurement of this value.

Procedure

Subjects were told what they were required to do before each series of similar tasks. The visual or auditory stimulus cueing the first task in that series was then displayed and the child's writing performance recorded. Subsequent tasks were cued until all the tasks in that series were completed. Instructions for the next series were then provided, stimuli presented and performance recorded until all 51 tasks were completed in one continuous session. Typically, this part of the evaluation took from 35 minutes to 45 minutes. All computerized data collection sessions were carried out by the same researcher.

Results

A similar style of presentation to the one used for Figure 1, is used to show one of the repeated English-like writing patterns (d from table 1) presented to the participants.

Figure 2a is the figure as it was presented on the computer screen, figure 2b was copied by a typical proficient handwriter and figure 2c was copied by a typical poor handwriter. In both figures, the heavy lines represent the actual trajectory of the child's pen when in contact with the writing surface; thin lines show the In Air trajectory, i.e., when the pen was above the writing surface.

*****Insert Figure 2 near here*****

When comparing the performance of the proficient writer to that of the poor writer during both the word and repeated pattern tasks, several key differences between the samples are apparent. The characters making up the poor handwriting sample are poorly spaced, and of irregular size and placement. The child appears to have found it difficult to draw straight horizontal lines, often veering upwards or downwards. Moreover, much of the trajectory occurs In Air, as noted by the abundance of thin lines.

The spatial characteristics of both word and repeated patterns were examined in detail for both proficient and poor handwriters. The first spatial variable to be presented is the mean total length traversed by proficient and poor handwriters when they copied writing tasks of different lengths (see Table 2). As expected, the mean total length increased as a function of task length (i.e., from 1 to 4 to 22 and to 100 characters).

To test for group differences (proficient versus poor handwriters) as a function of task length (single letters, words, sentences and paragraphs) for each dependent variable (e.g., total length, In Air length) the data were subjected to a series of one-way MANOVAs. The MANOVA applied to total length yielded a significant result across tasks ($F(4,91) = 8.88$, $p<.0001$). To examine the source of the significance, the data from each task were subjected to univariate ANOVAs. The results, shown in Table 2, indicated that the mean total length of word, sentence and paragraph tasks written by proficient handwriters was significantly shorter than that of the poor handwriters.

***** Insert Table 2 near here *****

The instrumentation used in this study enabled separation of total writing length into its two main components: the excursion on the surface of the paper (On Paper length) and the excursion above the surface of the paper (In Air length). Results of the MANOVA for On Paper length, shown in Table 2, yielded a borderline significant difference between the two groups ($F(4,91) = 2.44$, $p<.05$); subsequent univariate analysis showed that the significance was due to differences between the proficient and poor handwriters for the sentence and paragraph tasks.

In contrast, the MANOVA for In Air" length yielded significant differences between the two groups ($F(4,91) = 10.55$, $p<.0001$). As was the case for mean total length, mean In Air length increased as a function of task length for both poor and proficient handwriters, as shown in Table 2. It was determined via univariate analysis that the differences were significant for tasks of all lengths.

In order to determine whether In Air length increased as a function of task length or due to one or more other factors, we next examined In Air length as a percent of total length. The most notable finding, evident in Table 2, was that the In Air excursions of both poor and proficient handwriters comprised quite large percentages of the total excursion. Already when copying single characters, about 10% of the total writing length was In Air. When words with an average of 3.75 characters were copied, the percent In Air length rose to almost 50% of the total writing length for poor writers and almost 40% for proficient writers. In the case of paragraphs, about 70% of the writing length occurred In Air.

In order to gain deeper insight into the In Air phenomenon, we next analyzed the temporal and the spatial characteristics for a series of repeated writing patterns. As shown in Table 1, eight 5-character writing pattern sequences were grouped in accordance with the two criteria described above, Continuity, related to whether the characters in the task were presented discretely or continuously and Language, related to whether the characters were analogous to Hebrew or English letters. In Tables 3 and 4 are presented the results of a series of t-tests used to test for differences between the proficient and poor handwriters when they copied repeated writing patterns that varied in their Continuity (discrete or continuous) and Language (familiar or unfamiliar) characteristics for each dependent variable (i.e., total time and length, On Paper time and length, In Air time and length, and percent In Air time and length).

As shown in the Table 3, significant differences in total time between proficient and poor writers were found for both the continuous and discrete English-like tasks. Significant differences in total length were found for the discrete English-like tasks. There were no significant differences in either time or length for the Hebrew-like tasks.

*****Insert Table 3 near here*****

Table 3 also shows the results for On Paper time and length. It is evident from this table that there were significant differences between proficient and poor writers in time spent with the pen on the paper only for the English-like discrete writing patterns. No significant differences were found in any of the writing patterns in relation to the mean path length of the pen on the paper. In contrast, as shown in Table 4, there were significant differences for the In Air path lengths for the English-like continuous and discrete writing patterns. Finally, as shown in Table 4, significant differences between proficient and poor writers were found in the In Air time as a percent of total time for only the English-like continuous writing patterns. The results shown in Tables 2 through 4 demonstrate that the major differences between proficient and poor handwriters when they copied writing patterns occur In Air in both time and length.

***** Insert Table 4 near here*****

Examination of the percentage In Air time, shown in Table 4, indicated that in both the English-like and Hebrew-like continuous writing pattern tasks the pen remained above the writing surface for only about 10 to 20% of the total time. In contrast, for discrete writing patterns in both languages, this percentage increased to about 50% of the total time and 40% of the total length. The latter percentage is similar to that found when subjects wrote single words (cf. Table 2).

It is interesting to note that the within-group In Air path lengths and percent In Air length of the writing patterns differed so greatly. That is, both proficient and poor handwriters, spent much less time In Air when they copied continuous patterns as compared to when they copied discrete patterns, regardless of whether the pattern was familiar (Hebrew-like) or unfamiliar (English-like).

Finally, in order to examine any interaction effects that Continuity and Language had on the temporal and spatial variables, we used a mixed design (i.e., Continuity and Language were treated as within subject variables and group was treated as a between subject variable). The spatial and temporal variables were evaluated by ANOVA with repeated measures. A significant main effect was found for group (i.e., proficient versus poor handwriters) ($F(1,97)=6.99$ $p<.01$). A significant within-subject interaction effect was found for Continuity and Language interactions (F(1,97= 38.42, $p<.01$). Thus, for the continuous tasks, total time was longer when subjects copied familiar patterns than when they copied unfamiliar patterns and for the discrete tasks, the total time for unfamiliar tasks was longer than for familiar tasks. Finally, there was a significant between groups–within Language interaction ($F(1,97)=10.19$ $p<.01$). That is, the difference between proficient and poor handwriters for unfamiliar tasks was much higher than the difference between them for the familiar tasks.

Discussion

The objective of this study was to examine the temporal and spatial characteristics of pen movements that take place above the writing surface, and to show how these differ between poor and proficient Garde 3 handwriters. One of the major findings was the significant relationship between task length and both the temporal and spatial variables, particularly in the case of poor writers. For example, the In Air path length was significantly shorter for the proficient writers than for the poor writers for tasks that included letters, words, sentences, and paragraphs. The difference between the two groups increased significantly as task length increased from word to sentence to paragraph, becoming almost 75% of the total path length when poor handwriters wrote a 100 character paragraph.

The characteristics of a writing task are widely recognized as being important to a child's writing performance (Meulenbroek & Van Galen, 1984; Sovik, et al., 1987; Kosterman, et al., 1994; Smits-Engelsman & Van Galen, 1997). Factors such as allograph selection load (Smits-Engelsman et al., 1994a), familiarity with the writing pattern (Schoemaker & Smits-Engelsman, 1997) and contextual factors (Ellis, 1982; Wing, et al., 1983; Sovik et al., 1986, 1987) have all been shown to influence a child's handwriting. In the classroom, children are usually required to write sentences and paragraphs, rather than letters or single words. In keeping with Sovik, Arntzen, Samuelstuen, and Heggberget (1994) recommendations regarding the importance of using functional contexts to acquire deeper insight into children's handwriting, the tasks used in the present study were designed to mimic typical writing activities in the classroom. Thus, in this study, all writing tasks were performed while the children were in their classroom, seated in their regular chair and at their regular desk. Writing samples of letters, words, sentences and paragraphs were collected when the children copied texts displayed on a monitor. Additional tasks consisting of non-word letter sequences that were either connected or discrete, and familiar or non-familiar were also sampled. The resulting data enabled investigation of the effect of writing continuity and familiarity.

Data from the present study showed that, for both proficient and poor writers, the pen remained above the writing surface for a relatively short path length (about 10 to 20% of the total path length) when the repeated letter sequences were continuous. In the case of discrete, repeated letter sequences, the percent In Air path length increased considerably (to about 40-50% of the total path length). Part of this increase in percent In Air path length is to be expected since the child must raise his or her pen in order to progress from writing unit to unit when he is writing discrete characters. Indeed, Meulenbroek and Van Galen (1984) noted an important difference between cursive handwriting and discontinuous writing patterns comprised of successive acute angles. The writing of discontinuous patterns was inherently associated with the cessation of writing as each directional change was approached. They suggested that pauses may serve to give the young child an opportunity to plan the execution of the next segment, selecting its optimal size, speed and angle, as well as making adjustments in wrist and finger position. Further, they suggested that in the case of discontinuous writing patterns, the preparation and execution of movements may take place in a sequential manner whereas in continuous patterns preparation takes place while writing.

The introduction of familiar versus unfamiliar characters to the writing tasks containing either continuous or discrete letter sequences enabled the distinction between the part of the path length that stems from extrinsic factors (such as in moving the pen to get from one character to the next) and intrinsic factors (such as the planning how to write the next segment) In our study, significant differences between the two groups were found for the In Air path lengths for the unfamiliar, English-like writing patterns but not for the familiar, Hebrew-like writing patterns. When the writing patterns were discrete and familiar, there were no significant differences In Air path length between the proficient and poor writers. In contrast, when the writing patterns were discrete and unfamiliar, the poor writers had significantly longer In Air path lengths than had the proficient writers. When a discrete sequence is familiar to the writer, its effect on both proficient and poor handwriters is similar. Their writing time is increased due to the additional In Air path length. However, when the sequence or word is both discrete and unfamiliar it has a disruptive influence on poor handwriters.

These results extend our understanding over previous studies that have examined writing fluency; such studies have shown that children who are poor handwriters show greater variability in writing time (Wann & Kardirkamanathan,1991), take longer pauses between successive writing strokes (Wann,1987; Wann & Jones, 1986), employ greater force when writing (Wann, 1986), and are less accurate in the execution of characters (Hulstijn & Mulder,1986; Sovik et al., 1987; Schoemaker et al. 1994; Smits-Engelsman et al. 1994a;). It is important to note that one needs to be cautious when comparing the present results to those of previous studies of children with writing problems since the latter focused primarily on temporal variables such as total time (Schoemaker & Smits-Engelsman, 1997), speed (Sovik, et al., 1987) and the frequency of pauses (Wann & Jones,1986), rather than on the spatial variables presented here.

Smits-Engelsman et al. (1994a) examined the relationships between temporal and spatial variables of poor and proficient handwriters in a group of children aged 7 to 11 years. They found that poor writers differed from proficient writers in the duration of the pauses that followed the completion of both upstrokes and down-strokes. The poor writers also made more spatial errors than did the proficient writers. They suggested that proficient writers seem to succeed in finding strategies wherein they anticipate movement errors by making more corrections to the ongoing motor output. Poor handwriting may thus stem, in part, from a difficulty in spatial control. It may be that the extensive In Air motion tour observed in our results (cf., Figure 1) is one of the manifestations of what Smits-Engelsman, et al. (1994a) suggested to be the “variable, irregular or noisy character” of poor handwriters.

There also appears to be some evidence that task requirements have an effect on the frequency and duration of pauses (also referred to in the literature as breaks or a lack of fluency). Results similar to those presented in this paper were found by Schoemaker, et al. (1994) in their study of children with poor handwriting as well as gross and fine motor deficits. They found that these children drew more slowly, with less fluency and with longer pauses between strokes, especially when the complexity of the figures increased. In a subsequent study, Schoemaker and Smits-Engelsman (1997) found similar features (movement fluency, the duration of pauses between strokes and accuracy of drawing) in children with dysgraphia but no additional motor problems. These studies indicated that children with handwriting difficulties, with or without additional motor deficits, drew more slowly and with elongated pause intervals between strokes in comparison to typical children who had no writing problems.

A number of possible explanations of writing dysfluency have been proposed in the literature. Schoemaker, et al.(1994) introduced the idea that such movements are, perhaps, an expression of a need for greater visual feedback. Hulstijn and Mulder (1986) as well as Wann (1987) have suggested that children with writing problems in general, and clumsy children, in particular, are aware of the inaccuracy of their performance and use visual feedback to try to enhance their performance. This need is indicated by a higher incidence of ‘step’ and ‘ramp’ movements, which consist of a number of small intra-movement steps and a slow, gradual deceleration phase respectively (Hay, 1979; 1984). On the other hand, Schoemaker, et al. (1994)

considered that handwriting dysfluency may stem from biomechanical factors. For instance, a biomechanically unstable or "noisy" system will produce more natural oscillations which show up as dysfluencies in the velocity signal.

Another source of the difference between proficient and poor writers in the duration of between stroke pauses may be related to memory deficits. Schoemaker, et al. (1994) found that clumsy children looked at the monitor more frequently than did control subjects (they consulted the screen on more than one occasion prior to making a stroke for 25% of the trials). In contrast, the control children looked repeatedly at the screen only during 11% of the trials. Moreover, the clumsy children consulted the screen more often in the case of more complex figures. The researches subsequently rejected this "memory deficit" explanation because they found differences between the groups also for the less complex figures. They postulated that the differences could stem from the finding that clumsy children may be less capable of perceiving complex visual patterns as suggested by Lord and Hulme (1987). More research is needed to verify the effect that a deficit in memory may have on writing fluency.

Finally, Schoemaker, et al. (1994) suggested that differences in pause frequencies may also be explained in terms of Van Galen, et al.'s model (1991). As noted above, the drawing movements of clumsy children were slower and less fluent than those of control subjects. This suggests that clumsy children may devote considerable attention to the construction of the immediate stroke thereby detracting from their readiness to plan and produce the next stroke. If true, clumsy children may need to program the next stroke during the pauses between successive strokes, which would help explain the presence of the long between-stroke pauses observed in our study. What Schoemaker and Smits-Engelsman's (1997) refer to as "psychomotor-process deficiency" by the poor writers, may be the phenomenon we describe as differences between poor and the proficient writers in "in air" time and length.

Smits-Engelsman, et al. (1994a) have also suggested three possible explanations for the "dysfluencies" or the "noise" phenomenon that characterizes poor handwriting. The first is that poor handwriting may reflect a breakdown of kinesthetic input to the inhibitory system (Laszlo, Bairstow, & Bartrip, 1988; Laszlo & Broderick, 1991) or a breakdown in visual feedback processing (Askov, Otto, & Askov, 1970; Peck, Askov, & Fairchild,1980). Their second suggestion was that poor handwriting might be a product of a general cognitive deficiency that becomes manifest when children attempt to combine abstract mental operations (such as those involved in the use of language) with the act of writing. This is an aspect of writing that is also discussed by Abbott and Berninger (1993) who described some of the cognitive processes involved in reproducing letter forms such as the ability to attach verbal labels (name) to the forms, having an accurate, precise representation of the letter form in memory, and being able to access that letter form in memory and retrieve it. Smits-Engelsman et al.'s (1994a) third explanation was that poor writers, rather than being motorically impaired, suffer from a delay in psychomotor maturation.

In the current study, we examined a group of "just" mature handwriters, ranging in age from 8 and 9 years. Levine (1993) described stages of writing mastery and wrote that children at these ages perform at one stage prior to the "automatization stage" that takes place at Grades 4 through 7. Smits-Engelsman, et al. (1994b) found that motor retrieval is the process that is most likely to reflect developmental maturation, in particular at the ages of eight and nine years. Thus it may be that the In Air phenomenon, so pronounced in both our groups of subjects, but particularly amongst the poor handwriters, may stem from their age and maturational level. It is recommended that a longitudinal study be performed that studies the maturation of handwriting characteristics of children and assesses how much of the writing dysfluency stems from a maturational lag and how much constitutes an actual handwriting deficit. In this vein, Smits-Engelsman and Van Galen (1997) performed a study comparing poor and proficient handwriters in Grades 2, 3, and 4 (ages ranging from 8-10 years) in which they found that the poor writers did not catch up with their peers within the one-year time span tested. Their results seem to indicate that poor psychomotor skill persists in individual children over time, at least for a one-year time span.

These and previous results highlight writing difficulties that are apparent when the child is unable to form the letters in a fluent and mechanical manner. They require significantly greater time to carry out writing tasks and the product is insufficiently legible. We and others have found that at least part of the problem is related to an excess of In Air writing, a phenomenon that appears to represent the child's inability to progress automatically from segment to segment and letter to letter. It is evident that children who write poorly are in need of handwriting remediation, and that one of the major needs is related to helping them achieve greater automaticity when they write.

Remediation such as teaching children the details of letter formation may help them achieve a mastery of the mechanics of writing. This remediation should be based on the results of quantitative evaluation as well as consultation with the child regarding his awareness and opinion of his own performance of the evaluation tasks. Teaching children start and stop points, size, and directional changes for each letter and letter segment may help them develop and preserve the motor program of the letter, a fact that may make its retrieval during writing more efficient. Hence they would be free to think about the content of writing (Berninger, at al., 1997). Providing children with remediation techniques to become familiar with the letters may influence their “in air” path length in writing sentences and paragraphs and hence make their writing more functional. For example, Berninger, et al., (1997) suggested different kinds of cues or prompts that would be most helpful in automatizing the letter formation process, some of which comply with the possible explanations of the pause phenomenon suggested by Schoemaker et al. (1994) and Smits-Engelsman et al. (1994a) including methods based on the provision of motoric cues, visual cues, memory retrieval, the visual cues plus memory (Graham & Harris,1989) and the copy instructional approach. Of these possible instructional methods, the visual cues plus memory approach was the most effective intervention for improving both handwriting and compositional fluency in Grade 1 children (Berninger, et al., 1997), despite the fact that problems with visual memory were considered by Schoemaker, et al. (1994) to be less likely the source of writing dysfluency. Nevertheless, despite the progress that has been made in the development of instructional methods for writing remediation, there is, to date, no clear understanding of the causes of such dysfluencies in writing, nor how they vary amongst different groups of children. Further research directed towards the identification of the source of writing dysfluency is needed in order to provide a more substantial theoretical basis for handwriting intervention.

Acknowledgements: We would like to thank Dr. Esther Adi-Japha for her creative work in designing and programming the data collection and analysis program. We also thank Yaron Segal for development of the Matlab analysis modules, Gil

Rosenzweig for assistance with the research design and statistical analysis, and Sarina Goldstand for editorial assistance. Financial support from the Israeli Ministry of Education is gratefully acknowledged.

Tables

Table 1: Different types of writing patterns. Eight 5-character writing pattern sequences grouped in accordance with two key criteria, Continuity, related to whether the characters in the task were presented discretely or continuously and, Language, related to whether the characters were analogous to Hebrew or English letters.

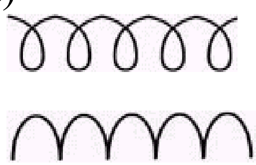
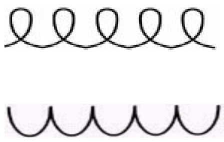
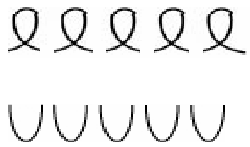
		CONTINUITY	
		Continuous	Discrete
LANGUAGE	Hebrew-like	(a) 	(b) 
	English-like	(c) 	(d) 

Table 2: Comparison of proficient and non-proficient writers. The mean total length, mean On-Paper path length (in millimeters), mean In Air path length, and mean In air length as a percent of total length (in percent) plus or minus one standard deviation taken for proficient and non-proficient handwriters to complete the four types of writing tasks when copying from text displayed on screen. The values represent means of all the tasks of a particular type (i.e., the mean seven different letters, four different two to five character words, two different 22 character sentences and one 100 character paragraph).

Variable	Task	Proficient M	Proficient SD	Non-proficient M	Non-proficient SD	*p*
Mean total path length (mm)	Letter	17.1	5.4	19.5	7.7	ns
	Word	63.0	12.9	82.7	26.7	<.01
	Sentence	457.6	106.2	683.8	241.8	<.01
	Paragraph	3029.4	569.9	4191.9	1331.2	<.01
Mean On paper path length (mm)	Letter	15.0	4.3	16.0	5.8	ns
	Word	37.3	5.8	40.1	12.8	ns
	Sentence	175.4	33.8	200.9	47.3	<.01
	Paragraph	978.4	178.5	1079.3	292.5	<.05
Mean In Air path length (mm)	Letter	2.1	2.1	3.6	4.2	<.05
	Word	25.7	10.5	42.6	19.8	<.01
	Sentence	281.1	87.7	482.8	221.3	<.01
	Paragraph	2051.0	467.8	3112.6	1191.6	<.01
Mean In Air length as a percent of total length (percent)	Letter	9.4	4.3	11.6	7.9	ns
	Word	37.5	7.6	47.0	10.8	<.01
	Sentence	60.9	5.5	68.4	8.4	<.01
	Paragraph	67.3	4.8	73.1	6.6	<.01

Figurs

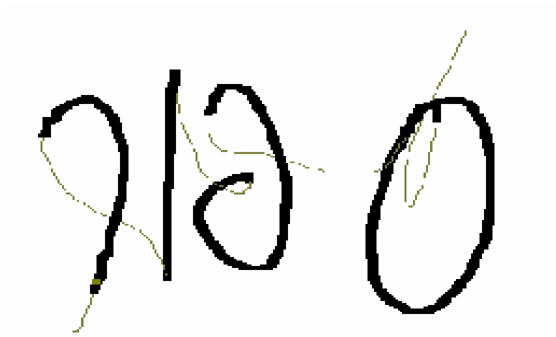
Figure 1: Hebrew handwriting sample.

Figure 1a shows a 4-letter Hebrew word as displayed on a computer monitor. The same word as written by a proficient handwriter (1b) and as written by a poor handwriter (1c) are shown. Heavy lines show when the pen was in contact with the paper; thin lines show when it was “in air”.

1(A) Example on the computer screen:

ספור

1(B) Proficient writer



1(C) Poor writer

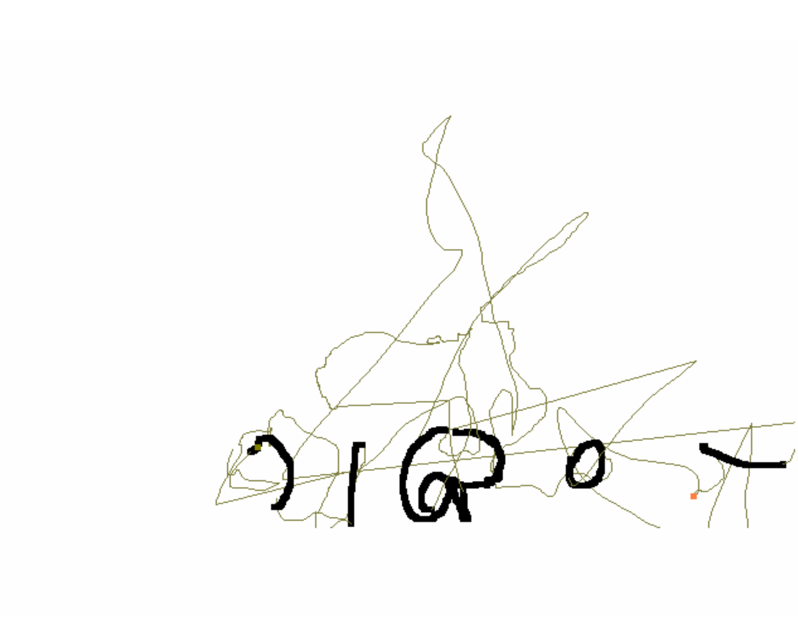


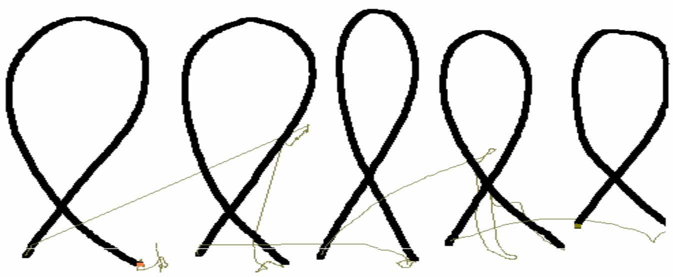
Figure 2: English-like, discrete writing pattern.

Figure 2a shows a 5-character discrete writing pattern as displayed on a computer monitor. The same pattern as written by a proficient handwriter (2b) and as written by a poor handwriter (2c) are shown. Heavy lines show when the pen was in contact with the paper; thin lines show when it was "in air".

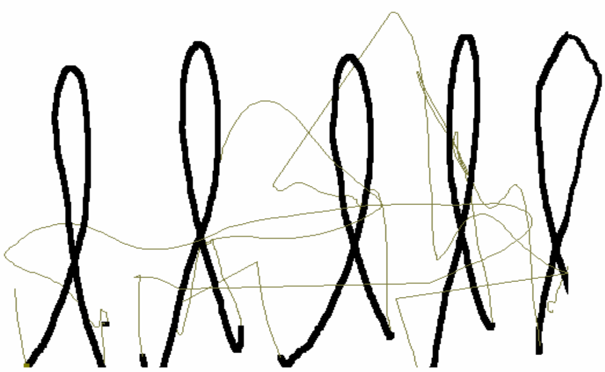
2(A) Example on the computer screen:

:

2(B) Profocient



2(C) Poor



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