The functional skill of handwriting is vital for accomplishing academic tasks that require writing, enabling students to express themselves legibly and efficiently through written assignments that they can complete in a timely manner (Amundson & Weil, 2001). Typically, elementary school children spend up to half their school day engaged in writing tasks, some of which (e.g., paper and pencil tests) are performed under the constraints of time (Amundson & Weil, 1996; McHale & Cermak, 1992; Tseng & Chow, 2000). Therefore, a child's ability to write in a manner that is both legible and efficient, directly affects his or her school performance and academic advancement (Amundson & Weil, 1996; Phelps, Stempel, & Speck, 1985; Tseng & Cermak, 1993; Tseng & Hsueh, 1997).

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 et al., 1985). In contrast, children who experience handwriting difficulties may find that it takes them longer than their peers to complete their assignments and that they are limited in terms of compositional fluency and quality. Such children can experience difficulties in expressing their thoughts and ideas, and may even receive lower marks for their work on the basis of its diminished legibility rather than its content (Amundson & Weil, 2001). Thus, it has been suggested that children with writing difficulties may suffer serious consequences not only in their academic progress, but also in their emotional well-being and social...
functioning (Cornhill & Case-Smith, 1996; Kaminsky & Powers, 1981; Modlinger, 1983).

Studies have indicated that handwriting dysfunction among school-aged children is a widespread and significant phenomenon. Smits-Engelsman, Van Galen, and Michelis (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 and Henderson (1982) who estimated that 12%–21% of elementary students in England displayed problems related to writing legibility or speed. Considering the potential impact of handwriting problems on one of the main activities that occupies children, and the frequency with which it occurs, the knowledge and expertise of occupational therapists places them in a position to play an important role in choosing the most appropriate handwriting evaluations and in providing effective intervention for schoolchildren who are experiencing handwriting difficulty.

Despite the considerable consequences that non-proficient handwriting appears to have on a 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). Traditionally, the primary outcome measures of impaired handwriting studies have been handwriting legibility (e.g., consistency of letter form, size, and spacing) and speed (e.g., the number of characters a child is able to write in 1 minute or the total time taken by a child to complete a given text of a predefined number of characters) (Amundson, 1993; Hamstra-Bletz, DeBie, & Den Brinker, 1987; Phelps et al., 1985; Reisman, 1991, 1993; Rubin & Henderson, 1982; Ziviani & Elkins, 1984; Ziviani & Watson-Will, 1998). Results from these studies are often difficult to compare due to variations in (1) task type (e.g., writing from memory or copying), (2) task length (e.g., writing single letters, words, or sentences), and (3) instructions given to the participant (e.g., “Write as fast as you can” versus “Write at your usual pace”) (Ayers, 1912; Freeman, 1959; Graham & Weintraub, 1996; Groff, 1961; Larsen & Hammill, 1989; Phelps et al., 1985; Phelps & Stempel, 1987; Tseng & Hsueh, 1997; Wallen, Bonney, & Lennox, 1996; Ziviani, 1984; Ziviani & Watson-Will, 1998). Moreover, the tools used in these studies were not suited to the measurement of any temporal variables other than handwriting speed, and they did not require participants to complete tasks of differing length and complexity. A further limitation is that almost all studies to date have been carried out with participants who have written using Latin-based character sets; the generalizability of speed norms from such studies to other languages is not known (Tseng & Hsueh, 1997).

Recent developments in data collection technology now permit the examination of a much richer 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., Smits-Engelsman & Van Galen, 1997; Smits-Engelsman, Van Galen, & Schoemaker, 1998; Sovik, Arntzen & Thygesen, 1987a, 1987b; Wann & Jones, 1986). The use of such devices enables the researcher to achieve greater precision or detail in the temporal dimension (e.g., the amount of time that a child holds the 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. In addition, other variables such as the pressure exerted on the writing surface, and the angle with which the pen is held can all be monitored in real time. Moreover, additional algebraic analyses such as calculating derivatives to obtain the acceleration of writing and or examining the output in the frequency domain are straightforward (Smits-Engelsman & Van Galen, 1997). 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 changes in a child’s handwriting as a function of fatigue, task complexity, or text presentation modality.

Temporal characteristics of non-proficient writers who were requested to write letters or words or to copy figures have been measured previously via digitizer technology (Schoemaker, Schellekens, Kalverboer, & Kooistra, 1994; Schoemaker & Smits-Engelsman, 1997; Smits-Engelsman, Van Galen, & Portier, 1994; Smits-Engelsman & Schoemaker, 1998; Smits-Engelsman, Niemeijer, & Van Galen, 2001; Smits-Engelsman & Van Galen, 1997; Sovik et al., 1987b; Wann & Jones, 1986; Wann & Kardikmanathan, 1991). The main features of the writing process of non-proficient writers found in these studies included variability in writing time and lack of continuity and fluency (Sovik et al., 1987b; Wann & Jones, 1986; Wann &
The objective of this study was to show how computerized digitizer technology enables a more in-depth study of the temporal characteristics of the writing of proficient and non-proficient handwriters. The specific research questions were (1) What are the temporal characteristics of handwriting as performed by third-grade children? (2) How do these temporal characteristics differ between proficient and non-proficient handwriters?

Methods

Study Design

This study used a cross-sectional design in which the handwriting performance of two groups of children was compared. The first group included children who were non-proficient handwriters and the second group included proficient handwriters who were matched to the first group by age, sex, and classroom. Each child was tested during one 45-minute session carried out at his or her school. 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), “on paper” time, and mean writing speed. Other variables such as the mean “in air” time as a percent of total time and total time divided by number of characters were derived from these primary measures.

Participants

Two groups of handwriters (proficient and non-proficient), each group consisting of 50 third-grade pupils, ages 8 and 9 years old, were recruited from eight 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 were right-hand dominant. 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 handwriting development literature 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 (Berninger et al., 1991; Levine, 1987). A lack of these qualities at this age may be a sign of a problem.

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, Jessel, Adi-Japha, Parush, & Weiss, 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 (Alston, 1983; Cornhill & Case-Smith, 1996; Rubin & Henderson, 1982). The Teacher’s Questionnaire for Handwriting Proficiency was content validated through a table of specifications by 10 experienced occupational therapy handwriting clinicians and researchers.

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 the Teachers’ Questionnaire for Handwriting Proficiency, they were tested with the Hebrew Handwriting Evaluation (HHE) (Erez & Parush, 1999), a standardized, reliable, and valid handwriting assessment for the Hebrew language. The HHE provides normative data for second and third graders. During test development, reliability and validity were established and are reported in the test manual (Erez & Parush, 1999). Internal consistency was high, Cronbach α = .81, and interrater reliability ranges from r = .71–.79. Validity was demonstrated through factor analyses and statistically significant differences on the HHE scores across subject groups (proficient and non-proficient handwriters), and across school grades (second and third) (p < .013–p < .000). No significant differences were found for gender. One hundred percent agreement between the Teachers’ Questionnaire for Handwriting Proficiency (Rosenblum et al., 1997) and the HHE (Erez & Parush, 1999) was found. Seventy percent of the children on both groups were boys, a gender bias that has been reported in the literature for children in England (Rubin & Henderson, 1982) and the Netherlands (Smits-Engelsman, Van Galen, & Michelis, 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, the 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 (8.68 ± 0.27 years for the proficient handwriters and 8.61 ± 0.35 years for the non-proficient handwriters) and gender ratio (30% girls versus 70% boys in both groups).
Instrument

Digitizing Tablet and Online Data Collection and Analysis Software

A suite of online, computerized tasks developed via Matlab (3 Apple Hill Drive, Natick, MA 01760-2098, USA) data collection and analysis 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). A digitizing tablet is an electronic surface that records the “x” and “y” coordinates when an electronic pen comes in contact with its surface or within 5 mm of its surface. The electronic pen used in this study was of a size and weight similar to that of pens typically used by children of this age (length = 150 mm, circumference = 35 mm, weight = 11 gm). The paper was lined (spacing = 0.5 cm).

Handwriting Tasks

The suite of handwriting tasks, which were graded in type and complexity, ranged from single characters to words, sentences, and paragraphs. The tasks were presented visually on the screen in Hebrew font type Gutman Yad-Brush size 20 point (shown in Figure 1A). The items were selected to represent handwriting tasks in which a child would typically engage. The tasks analyzed 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.

Procedure

All participants performed the experiment under similar environmental conditions in a quiet classroom in their school. Each participant was tested individually during the morning hours. The participant was seated on a standard school chair and in front of a school desk that were appropriate to his or her height. The tasks were written on normal writing paper with printed lineature, which was affixed to the digitizing tablet. Each participant was instructed in the same fashion about what he or she would be required to do. The testing took approximately 25 minutes. All computerized data collection sessions were administered by the same person.

Analysis

MANOVA analyses were used to test for the group differences (non-proficient versus proficient handwriters) across tasks (single letters, words, sentences, and paragraphs) for each dependent variable (total time, “on paper” time, “in air” time, mean writing speed). To examine the source of the significant differences between groups, the data from each task were subjected to univariate analysis of variances (ANOVAs).

Results

Shown in Figure 1 are three representative examples of one of the target sentences, “Eretz Yisrael sheli yaffa v’gam porachat” (translation: “The land of Israel is beautiful and blooming,” part of the refrain from a popular Israeli song that would be familiar to Israeli school children). Figure 1A shows this 22-character sentence as presented to participants on the computer screen. The lower two panels of the figure show two examples of the same sentence as written by a proficient (1B) and a non-proficient (1C) handwriter.

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). A visual examination of the extent of the thin line trajectories (indicating time spent “in air”) shown in each of these handwriting samples reveals that the amount of time spent “in air” by the child with non-proficient handwriting is considerably greater than that by the proficient handwriter.

Total Time

The first temporal variable to be examined in detail was the mean total time taken by proficient and by non-proficient handwriters to complete copying tasks of different lengths.
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). The MANOVA applied to mean total time yielded a statistically 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 four task types than did the non-proficient handwriters.

### Time per Character

We thought it important to examine whether the mean time taken to write characters was influenced by the overall length of the task. We therefore divided the total time taken to complete each task by the total number of characters in that task. The results of this procedure, referred to as the “mean time per character,” are shown in Table 1. The MANOVA for this variable yielded significant differences \( F(4,91) = 14.63, p < .0001 \) 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 non-proficient and proficient handwriters. The results of the univariate analysis showed that proficient handwriters had significantly less “in air” time while engaged in the four task types than did the non-proficient handwriters (see Table 1).

### “In Air” Time

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 \( F(4, 91) = 13.63, p < .0001 \) between the two groups. As was the case for mean total time, “in air” time increased as a function of task length for both the non-proficient and proficient handwriters. The results of the univariate analysis showed that proficient handwriters had significantly less “in air” time while engaged in the four task types than did the non-proficient handwriters (see Table 1).

### “In Air” Time as a Percent of Total Time

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. 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 analysis showed that proficient handwriters had significantly less “in air” time while engaged in the four task types than did the non-proficient handwriters (see Table 1).

### Table 1. Comparison of Proficient and Non-Proficient Writers.

The mean total writing time, mean time per character, mean “in air” time (in seconds), mean “in air” time as a percent of total time (in percent), and mean speed 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).

<table>
<thead>
<tr>
<th>Task</th>
<th>Variable</th>
<th>P</th>
<th>Non-proficient (Mean ± SD)</th>
<th>Proficient (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Letter</td>
<td>Mean total writing time</td>
<td>&lt; .011</td>
<td>1.62 ± 0.84</td>
<td>1.27 ± 0.46</td>
</tr>
<tr>
<td>Word</td>
<td>Mean time per character</td>
<td>&lt; .001</td>
<td>5.64 ± 2.16</td>
<td>3.3 ± 0.92</td>
</tr>
<tr>
<td>Sentence</td>
<td>Mean “in air” time as a percent of total time</td>
<td>&lt; .001</td>
<td>46.66 ± 22.80</td>
<td>23.37 ± 7.06</td>
</tr>
<tr>
<td>Paragraph</td>
<td>Mean speed</td>
<td>&lt; .001</td>
<td>313.12 ± 131.07</td>
<td>171.29 ± 55.85</td>
</tr>
<tr>
<td>Letter</td>
<td>Mean total writing time</td>
<td>&lt; .011</td>
<td>1.62 ± 0.84</td>
<td>1.27 ± 0.46</td>
</tr>
<tr>
<td>Word</td>
<td>Mean time per character</td>
<td>&lt; .001</td>
<td>1.50 ± 0.58</td>
<td>0.88 ± 0.24</td>
</tr>
<tr>
<td>Sentence</td>
<td>Mean “in air” time as a percent of total time</td>
<td>&lt; .001</td>
<td>2.12 ± 1.04</td>
<td>1.06 ± 0.32</td>
</tr>
<tr>
<td>Paragraph</td>
<td>Mean speed</td>
<td>&lt; .001</td>
<td>2.95 ± 1.24</td>
<td>1.62 ± 0.53</td>
</tr>
<tr>
<td>Letter</td>
<td>Mean total writing time</td>
<td>&lt; .029</td>
<td>0.30 ± 0.41</td>
<td>0.16 ± 0.14</td>
</tr>
<tr>
<td>Word</td>
<td>Mean time per character</td>
<td>&lt; .001</td>
<td>2.87 ± 1.49</td>
<td>1.41 ± 0.53</td>
</tr>
<tr>
<td>Sentence</td>
<td>Mean “in air” time as a percent of total time</td>
<td>&lt; .001</td>
<td>34.14 ± 20.06</td>
<td>14.93 ± 5.83</td>
</tr>
<tr>
<td>Paragraph</td>
<td>Mean speed</td>
<td>&lt; .001</td>
<td>246.17 ± 117.79</td>
<td>123.78 ± 47.79</td>
</tr>
<tr>
<td>Letter</td>
<td>Mean total writing time</td>
<td>&lt; .17</td>
<td>15.48 ± 12.64</td>
<td>12.41 ± 8.27</td>
</tr>
<tr>
<td>Word</td>
<td>Mean time per character</td>
<td>&lt; .011</td>
<td>49.25 ± 11.23</td>
<td>42.46 ± 9.84</td>
</tr>
<tr>
<td>Sentence</td>
<td>Mean “in air” time as a percent of total time</td>
<td>&lt; .001</td>
<td>70.32 ± 9.29</td>
<td>62.73 ± 7.42</td>
</tr>
<tr>
<td>Paragraph</td>
<td>Mean speed</td>
<td>&lt; .001</td>
<td>76.88 ± 7.49</td>
<td>71.07 ± 5.82</td>
</tr>
<tr>
<td>Letter</td>
<td>Mean total writing time</td>
<td>&lt; .42</td>
<td>15.45 ± 6.95</td>
<td>14.44 ± 6.21</td>
</tr>
<tr>
<td>Word</td>
<td>Mean time per character</td>
<td>&lt; .004</td>
<td>17.38 ± 6.15</td>
<td>22.89 ± 6.05</td>
</tr>
<tr>
<td>Sentence</td>
<td>Mean “in air” time as a percent of total time</td>
<td>&lt; .001</td>
<td>18.50 ± 6.81</td>
<td>22.57 ± 6.05</td>
</tr>
<tr>
<td>Paragraph</td>
<td>Mean speed</td>
<td>&lt; .013</td>
<td>18.13 ± 6.22</td>
<td>22.31 ± 5.93</td>
</tr>
</tbody>
</table>

The American Journal of Occupational Therapy
time as a percentage of total time were much smaller (see Table 1). For example, whereas non-proficient 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 (246.17 s versus 34.14 s), there was only a difference of 7.5% when percents for the same tasks are compared (76.9% versus 70.3%). It is thus evident that increases in task length are associated with greater time spent “in air.”

The most important result of the “in air” data described above is the fact that both non-proficient and proficient handwriters spent 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. Non-proficient handwriters spent about 77% of the total writing time “in air” at the same task.

Examination of numerous handwriting samples such as the four-character word shown in Figure 2 suggested that the non-proficient handwriters did not simply hold their pens stationary while their pencils were “in air.” Shown in Figure 2A is one of the four-character words that participants copied during one of the tasks. A sample from a non-proficient handwriter is shown in Figure 2C; the thick line indicates when the child’s pencil is on the writing surface and the thin line indicates when it is above the writing surface. This sample illustrates this group’s tendency to meander about above the writing surface prior to, following, and even during the writing of each character. In contrast, “in air” trajectories of proficient handwriters such as the child whose sample is shown in Figure 2B were considerably more circumscribed.

**Speed**

We next examined the mean speed of writing during all tasks. Mean velocities for both the proficient (16.4 mm/s) and non-proficient (15.4 mm/s) handwriters were lower when writing single letters as compared to the writing of words, sentences and paragraphs. The MANOVA for this variable yielded significant differences \[ F(4,91) = 5.99, p < .0002 \] between the two groups. For these latter tasks, proficient handwriters wrote with speeds of about 22–23 mm/s which were significantly faster than the speeds of about 17–18 mm/s achieved by the non-proficient handwriters for these same tasks.

Differences between proficient and non-proficient handwriters in the time they needed to complete longer handwriting tasks highlights the comparison between the two groups in a manner commonly used in educational settings, that is the number of characters written per minute (calculated by dividing the total number of characters in a 100-character paragraph by the total time it took participants to complete that task). On average, the proficient handwriters wrote 41.12 ± 13.26 characters per minute whereas the non-proficient handwriters wrote only 24.28 ± 10.54 words per minute. This difference was highly significant \[ t(98) = 6.93, p < .0001 \].

**Discussion**

In the current study handwriting samples of progressively increasing length were recorded in real time via an x–y digitizing tablet with the aim of comparing the temporal characteristics of the handwriting of non-proficient handwriters to that of matched control children. The major finding was that the non-proficient handwriters performed significantly less well on all of the tested temporal variables than did their peers. For most variables these differences were already apparent when the participants 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 mean speed, measured both in millimeters per second and as the number of characters per minute.

The finding that temporal variables differentiate between proficient and non-proficient handwriters is supported by results from studies that used traditional handwriting evaluation scales to measure writing speed. These studies usually focused on measuring writing speed by not-
ing the time taken to complete a given (standardized) writing passage, or by how much could 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 non-proficient handwriting, Wann and Jones (1986) did not find mean total time to be a good differentiator between two groups of proficient and non-proficient grade 4 and 5 children. However, when the data from only the grade 4 children were examined, a group close in age to the children in our study, the results were similar to our findings. No differences in mean writing speed were found between proficient writers, children diagnosed with dysgraphia, and children diagnosed with dyslexia of third-grade children (Sovik, Arntzen, & Thygesen, 1987a, 1987b) nor between these same three groupings of children aged 9 years old (Sovik, Maeland, & Karlstottir, 1989). When Smits-Engelsman et al. (2001) asked children to draw the flower-trail drawing item of the M-ABC test (Henderson, Stott, & Moyes, 1992) they found that non-proficient writers wrote with greater velocity and finished the task in less time than proficient writers. One explanation for this finding may be that the non-proficient handwriters who complete writing tasks more quickly than their peers do so at the cost of less legible output. It is likely that the differences in findings from the various studies are due to a variety of factors including instructions to the child and variations in task type and length; the effects of these variables should be examined in detail in future studies.

In the current study one of the variables that only the use of a digitizer makes possible, “in air” time has been examined in detail. The literature refers to this phenomenon as pauses, or temporary halts in the flow of writing, and it has been noted in clinical reports that non-proficient handwriters have a tendency to pause frequently while writing (Benbow, 1995; Kaminsky & Powers, 1981). However, due to a lack of a methodology for quantifying their observations, these findings did not provide any detail about what occurs during the handwriter’s pauses. It has, therefore, been difficult to further our understanding of why children pause, and whether pauses serve as an aid or a hindrance to the writing process. Do children merely rest their pens on the paper until they are ready to continue writing, or do they 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 sequela

Some researchers have suggested that handwriting is not “mechanical” or “automatic” for many young writers (Amundson & Weil, 1996; Berninger, Vaughn, Abbott, Rogan, Brooks, et al., 1997; Cermak, 1991; Oliver, 1990), 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 repetitive tasks composed of basic elements that would be expected to be performed more automatically.
Another issue that cannot be overlooked is the fact that our “in air” results were obtained from children who wrote in Hebrew. As indicated above, one of the features of the Hebrew language is that, even in cursive writing, successive letters are not connected; it may be that Hebrew handwriters engage in greater “in air” activity than do children who write in other languages simply as an artifact of the language itself. Only a comparative study of children who write in languages in which script is essentially disconnected (e.g., Hebrew, Arabic, Chinese) and in which it is almost entirely connected (e.g., English) will determine to what extent the “in air” phenomenon is universal, and one that differentiates dramatically (as in Hebrew) between non-proficient and proficient writers. It is interesting to consider the concept of “in air” time as an indicator of a lack of automaticity in view of Van Galen’s model of handwriting (Van Galen, 1991; Van Galen, Portier, Smits-Engelsman, & Shomaker, 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 (i.e., setting the values of the relevant motor program variables) 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.

In summary, we have shown that the use of a digitizer permits the collection and analysis of a wide variety of temporal variables, some of which would have been unattainable without this technology. Further examination of the temporal variables, and specifically the “in air” phenomenon, on a wider sample of children from different age groups, diagnostic categories, and cultures, will help to determine the implications of these results for occupational therapy intervention. If the present results prove to be generalizable to a wider population, therapists should consider incorporating these and other variables (e.g., displacement, pressure) that require the use of digitizer technology into clinical handwriting evaluations (Longstaff & Heath, 1997). ▲

Acknowledgments

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 Matlab analysis modules and Gil Rosenzweig for assistance with the research design and statistical analysis. Financial support from the Ministry of Education is gratefully acknowledged.

References


Downloaded from http://ajot.aota.org on 09/09/2019 Terms of use: http://AOTA.org/terms
The American Journal of Occupational Therapy


Wann, J. P. (1987). Trends in the refinement and optimization of fine-motor trajectories: Observations from an analysis of the...

Build Children’s Hand Skills

**Getting a Grip on Handwriting:** A Self-Guided Video and Manual

*Barbara Hanfi, MA, OTR/L, FAOTA, and Dottie Marsh, MS, OTR/L*

Use this practical 30-minute video and 25-page manual to devise appropriate intervention strategies for children with learning disabilities and/or mild motor impairments. It includes three sections:

1) Information related to hand anatomy and function essential for writing;
2) Guidelines for determining motor readiness for learning to print; and
3) Case vignettes of three children who have encountered problems learning to print or write in cursive.

**Order #1979-J**

$40 AOTA members

$50 nonmembers

**Development of Hand Skills in the Child**

*Jane Case-Smith, EdD, OTR/L, BCP, FAOTA, and Charlane Pehoski, MS, OTR, FAOTA, Editors*

Presents and explains the therapeutic approaches and strategies that enhance the development of hand skills and the child's ability to play, manipulate, and skillfully use tools. Also addresses the complexity of hand skill development and features treatment through upper-extremity casting for children with cerebral palsy.

**Order #1969-J**

$30 AOTA members

$37 nonmembers