Predicting Occupational Performance: Handwriting Versus Keyboarding

Fabia Preminger,
Patrice L. (Tamar) Weiss,
Naomi Weintraub

KEY WORDS
• handwriting
• keyboarding
• pediatrics

PURPOSE. To determine whether there is a correlation between handwriting and keyboarding speed and accuracy, and whether handwriting and keyboarding share common underlying components.

METHODS. Sixty-three typically developing 5th-grade students attended a series of 15 keyboarding lessons for a total of 5 hours. Prior to the lessons, cognitive, sensory, and motor skills related to handwriting were evaluated. Prior to and following the lessons keyboarding and handwriting accuracy and speed were also tested. Correlations were employed to examine relationships between handwriting and keyboarding skills and multiple regression analyses were used to examine the contribution of performance components to handwriting and keyboarding performance.

RESULTS. Following keyboarding instruction, a significant correlation was found between handwriting and keyboarding speed, but not in accuracy of these tasks. Similarly, some of the specific tests measuring tactile and oculo-motor functions were found to be related to both handwriting and keyboarding speed, yet accuracy of these tasks did not share common underlying components.

CONCLUSIONS. It appears that handwriting and keyboarding accuracy may entail different skills, suggesting that keyboarding may be a potential alternative writing tool for students with handwriting difficulties. It also appears that when students write slowly, handwriting speed should be considered prior to recommending keyboarding for these students. Additional research is required to further support these findings.

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Fabia Preminger, MSc, OT, was Graduate Student, School of Occupational Therapy, Hadassah and the Hebrew University, Jerusalem, Israel, at the time of the study.

Patrice L. (Tamar) Weiss, PhD, OT, is Associate Professor, Department of Occupational Therapy, University of Haifa, Haifa, Israel.

Naomi Weintraub, PhD, OTR, is Assistant Professor, School of Occupational Therapy, Hadassah and the Hebrew University, PO Box 24026, Mount Scopus, Jerusalem, Israel; msnwei@mscc.huji.ac.il

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Handwriting is one of the most important skills that children acquire and use throughout the school years (Graham & Weintraub, 1996) as part of their occupation as students. Between 10% to 20% of school-age children have problems with handwriting skills (Hamstra-Bletz & Blote, 1993; Rubin & Henderson, 1982). When handwriting skills are deficient, children suffer various consequences related to their academic performance (Graham & Weintraub, 1996; Phelps, Stempel, & Speck, 1985) and social interactions (Sandler et al., 1992), thus limiting their successful participation in everyday school activities. Many of these students are referred to occupational therapists, who apply various intervention models (Yinon & Weintraub, 2000).

In cases where children, despite intervention, are unable to achieve competence in handwriting performance, a compensatory approach such as computer keyboarding may be employed (Law, Baum, & Baptiste, 2002). Occupational therapists often play a role as consultants to parents and teachers of students with handwriting difficulties, and in the instruction of keyboarding skills. This role involves both assessing students' capacities required for keyboarding and participating in the decision about whether or not the student may benefit from the use of a computer for writing (Penso, 1999).

Using the computer for writing has several advantages. First, the final written product tends to be neater, more legible, and more accurate than a handwritten page (MacArthur, 1998; Waner, Behymer, & McCrary, 1992). Second, the writing process is often more efficient, since students can more easily correct typing and spelling errors (Margalit & Roth, 1989). Children are also less hesitant to reevaluate and edit their written work produced on the computer (Graham & MacArthur, 1988; Jones, 1994). As a result, the productivity (Mayer Nichols, 1996; Sormunen, 1988) and quality (Jones) of their written work may be increased. Finally, writing via the computer may improve students' attitudes towards learning to write (Balajthy, 1988; Waner et al.).

Computers, however, also have disadvantages when compared to handwriting. It is more difficult to write via keyboarding in specific settings such as in the library or on a field trip. Furthermore, computers are also not always available in the classroom (Kahn & Freyd, 1990). Moreover, many school-age children are not familiar with the keyboard arrangement. For these students, keyboarding may decrease their writing speed rather than accelerate it (Koorland, Edwards, & Doak, 1996), and the quality of their compositions may be affected (Waner et al., 1992). Such students may become frustrated when writing via a computer (MacArthur & Shneiderman, 1986; Neufeld, 1989).

Keyboarding, as in the case of handwriting (Graham & Weintraub, 1996), is a complex skill that requires the orchestration of linguistic, cognitive (Gopher & Raij, 1988), and sensory-motor skills (Sormunen, 1993). It is not a simple skill to acquire and maintain, and achieving fluency while keyboarding requires many hours of practice (Kahn & Freyd, 1990). Hence, when considering keyboarding as an alternative to handwriting, it is essential that occupational therapists be familiar with what these skills entail.

West (cited in Sormunen, 1993) described keyboarding acquisition as a process that involves three phases. The first, the *cognitive* phase, necessitates the learning and applying of different movement patterns for different keystrokes. At this phase, the learner relies on visual feedback, wherein he or she looks at the digits or at the screen immediately after hitting the key. In the second, the *associative* phase, the specific movement patterns acquired become integrated into the total skill. The learner relies more on internal feedback (i.e., kinesthetic cues). In the final, the *autonomous* phase, the learner relies primarily on kinesthetic feedback.

Keyboarding and handwriting also differ in certain aspects. For example, keyboarding requires the memorization of a large number of associations between spatial locations and verbal codes (Gopher & Raij, 1988), the positioning of the fingers on these locations and then the pressing of each key with great precision and timing (Cooper, 1982). In contrast, handwriting requires the matching of a motor program for the formation of a specific allograph (a specific formation of a letter) and then executing this program (van Galen, 1991). Handwriting also involves issues of spatial organization, which are not necessary while keyboarding.

The similarities and differences between handwriting and keyboarding skills bring to mind the question: Will children who have handwriting difficulties also have difficulties keyboarding? To date, there is not sufficient data to assist occupational therapists to predict which students would most benefit from using a computer as an alternative writing tool, thereby justifying keyboarding instruction. Only a few studies were found that address this issue. Kahn and Freyd (1990), for example, found that among typical 6th graders, students who were able to write quickly tended to type quickly. Results of a study by Rogers and Case-Smith (2002), which included forty 6th-grade students, indicated that keyboarding speed was significantly correlated with handwriting legibility and speed. However, there was no evidence indicating that handwriting and keyboarding require similar underlying components.

In contrast, several studies have shown the relationship between handwriting performance and various performance components, including linguistic abilities and specifically, orthographic fluency and coding (Abbott & Berninger, 1993), visual-motor integration (e.g., Cornhill & Case-Smith, 1996; Tseng & Chow, 2000; Weintraub & Graham, 2000), finger functions (Berninger & Rutberg, 1992), motor accuracy (Tseng & Murray, 1994; Yochman & Parush, 1998), and in-hand manipulation (Cornhill & Case-Smith, 1996). With respect to keyboarding, whereas several authors (e.g., Gopher & Raij, 1988; Sormunen, 1993) have suggested some of the underlying capacities that are required for this skill, empirical studies examining such relationships are rare. McClurg and Kercher (1989), for example, found that the strongest predictor for success on typing tests, among students in 3rd and 4th grade, was performance on dexterity measures such as finger and pencil tapping.

Understanding the relationship between handwriting and keyboarding skills and their shared and differing underlying performance components will assist occupational therapists to better understand these processes, and to determine which students with handwriting difficulties may benefit from keyboarding. The objective of this study was to further our understanding of keyboarding as an alternative tool for writing. This was accomplished by determining: (a) whether there is a correlation between handwriting and keyboarding speed and accuracy, and (b) whether similar performance components predict handwriting and keyboarding accuracy and speed.

Methods

This study applied a correlational research model examining the relationship between students' scores on various performance components and their occupational performance in handwriting and keyboarding.

Participants

Of the seventy-one 5th-grade students at an elementary school located in Israel, 63 boys and girls received parents' agreement to participate in this study. These students had not received any occupational, physical, or speech therapy throughout the past year, nor did they have any known motor, sensory, or behavioral problems. Most of the students came from average to high socioeconomic family backgrounds. The sample included 36 boys and 27 girls, with a mean age of 10.2 years (SD = .6). Four of the students were identified as having learning disabilities.

Instruments

The measures in this study were used to assess students' performance in three areas: (a) performance components thought to be related to handwriting and to the initial stages of touch-typing skills, (b) keyboarding, and (c) handwriting. Since we found practically no studies indicating what performance components are related to keyboarding skills, we used the Delphi technique to select components that should be included in this study (French, Reynolds, & Swain, 2001). For this purpose, letters were sent to 30 pediatric occupational therapists in Israel with over 5 years of experience, who serve as supervisors of students of the School of Occupational Therapy during their fieldwork, requesting that they list the performance components, which they believed to be necessary for handwriting and keyboarding. Twenty-seven replies were received.

Based on these replies, in the second stage of the process, a list of performance components was developed and sent to the same occupational therapists, asking them to rate the significance of each component to handwriting and keyboarding skills on a scale of 0 to 10. Twenty-five replies were received. In the third stage, the results of the occupational therapists' ratings were analyzed. Components considered significant by more than 50% of the occupational therapists (i.e., the component received a score of 8 or above) were selected. Finally, standardized tests, which measure the identified components, were selected for this study (see Table 1).

Table 1. Matching Performance Components With Standardized Tests.

Performance Components	Matching Standardized Tests
Sensory Components	
Tactile perception	Finger Lifting[a], Finger Recognition[a]
Kinesthetic ability	Pencil Excursion[b], Finger Lifting[a], Complex Finger Opposition[b], Recall Complex Finger Opposition[b]
Motor Components	
Finger isolation	Finger Lifting[a], Finger Recognition[a]
Bilateral coordination	Alternating Fists[b]
Eye–Hand coordination	Motor Coordination[c], Pencil Speed[b]
Visual Component	
Occulo-motor movements	Developmental Eye Movement (DEM)[d]
Perceptual-Cognitive Components	
Visual-motor integration	Visual Motor Integration[c]
Spatial perception	Left-Right Discrimination[b]
Motor planning	Alternating Fists[b], Complex Finger Opposition[b]
Visual perception	Recall Complex Finger Opposition[b]
Visual memory	Visual Perception[c], Visual Recognition[b]
Motor memory	Visual Recognition[b], Visual Retrieval[b] Recall Complex Finger Opposition[b]

Notes. [a]Finger tasks described by Berninger and Rutberg (1992). [b]Subtest of the Pediatric Examination of Educational Readiness at Middle School (PEERAMID) (Levine, 1984). [c]Subtest of the Developmental Test of Visual Motor Integration (VMI) (Beery, 1997). [d]See Garzia et al. (1990).

Performance Components Measures

Finger tasks. Two finger tasks were included in the study: Finger Lifting and Finger Recognition (Berninger & Rutberg, 1992). Both tasks measure tactile perception and finger isolation. Finger Lifting also requires a motor reaction while vision is occluded (kinesthetic ability) (Denckla, 1974). In the *Finger Lifting* task scoring is based on accuracy in lifting the correct fingers (maximum score is 4). Similarly, in the *Finger Recognition* task, scoring is based on accurately identifying the fingers that were touched (maximum score is 10). Berninger and Rutberg (1992) reported that these finger tasks significantly correlated with a handwriting task (p < .001) among students in primary grades. No other validity information was provided. In addition Berninger and Rutberg reported a high interrater reliability (r = .96 for Finger Lifting; r = .90 for Finger Recognition) among this age group. In this study, interrater reliability between two occupational therapists was established using Spearman Correlation coefficients as follows: Finger Lifting, r = .99, p < .01; Finger Recognition, r = .86, p < .01.

The Developmental Test of Visual Motor Integration (VMI; Beery, 1997) is a norm-referenced assessment that examines visual-motor integration and includes three subtests: (a) Visual Motor Integration, (b) Motor Coordination, and (c) Visual Perception. In the *Visual Motor Integration* subtest, students were requested to copy 27 geometric forms. The maximum total raw score for this subtest is 27. In the *Visual Perception* (VP) subtest of the VMI children were required to correctly identify specific forms (which are the same as those in the VMI subtest) within 3 minutes. For each correctly identified form, a score of 1 is awarded. The maximum total raw score for this subtest is 27. The *Motor Coordination* (MC) subtest of the VMI measures eye–hand coordination. The maximum total raw score for this subtest is 27. The authors report high validity and reliability for the test (for details see Beery).

Pediatric Examination of Educational Readiness at Middle Childhood (PEERAMID) (Levine, 1984). The PEERAMID is a neurodevelopmental assessment that is meant for children between the ages of 9 and 15 years. Of the 32 subtests of the PEERAMID, 8 were included in this study due to the fact that they measure the specific performance components that were selected by the occupational therapists as related to handwriting and keyboarding skills.

The *Left-Right Discrimination*, a subtest of the PEERAMID, is a measure of spatial perception and orientation. This subtest includes five tasks, each receiving a separate score, with a total possible score of 5.

The *Alternating Fists* subtest of the PEERAMID measures bilateral coordination and motor planning. In this subtest, a score of 1 represents a well-coordinated, clear alternation of movements; and 0 represents incorrect, poorly coordinated alternation of movements.

The *Complex Finger Opposition* subtest of the PEERAMID evaluates kinesthetic ability and motor planning while performing a specific finger sequence using finger opposition. The total possible score is 3.

The *Pencil Speed* subtest of the PEERAMID examines eye–hand coordination. Scoring was as follows: Each completed unit and contact points in the intersection were recorded. Intersection points were subtracted from total units. In case of a negative total number (i.e., more contact points in the intersection than completed units), the score was recorded as zero.

The *Pencil Excursion* subtest of the PEERAMID rates students' kinesthetic ability as well as motor memory and accuracy. The score is based on the number of squares drawn correctly, in the three lines drawn with eyes closed. This is calculated by counting the number of squares drawn in each of the three lines (including deviations from the lines) and subtracting the number of squares expected to be drawn. Therefore, a lower score represents a better performance.

The *Visual Recognition* subtest of the PEERAMID assesses visual perception and memory. A score of 1 was given for each correct response, and 0 for each incorrect response. The total possible score is 4.

Similarly, the *Visual Retrieval* subtest of the PEERAMID evaluates visual perception and memory. Each design is composed of a few parts, and each is scored separately, with a score of 1 for each correct, and 0 for an incorrect response. The total possible score is 22.

The *Recall Complex Finger Opposition* subtest of the PEERAMID rates students' motor memory and kinesthetic ability. The total possible score is 1.

Although there was no literature found regarding the reliability and validity of the PEERAMID, a study by Sandler et al. (1992) found that many of the subtests of the PEERAMID, including those that were included in this study were associated with handwriting performance. In this study, interrater reliability was calculated for the subtests that are scored while the students perform the tests. Correlation coefficients (using Spearman correlations) ranged from .66 to 1.00.

The *Developmental Eye Movement Test* (DEM; Garzia, Richman, Nicholson, & Gaines, 1990) assesses oculomotor movements while reading single digits aloud from top to bottom (vertical) and then from left to right (horizontal) as quickly as possible. The time required for completing each of the tasks and the number of errors (including additions, omissions, and substitutions of numbers) are recorded. Construct validity was demonstrated as DEM performance time decreased with age, demonstrating that the DEM reflects developmental changes. In addition, internal consistency was found when most subtests of the DEM significantly correlated with each other ($.24 < r < .75$). Finally, significant test–retest coefficients for the DEM (with 1 week interval between the tests) ($r = .89$ for vertical time and $r = .86$ for horizontal time) were reported (Garzia et al., 1990). In the current study the interrater reliability using Pearson correlations were as follows: $r = .99$ ($p < .01$) for DEM vertical and $r = .94$ ($p < .001$) for DEM horizontal.

Handwriting and Keyboarding Ability

Handwriting quality was measured using *The Hebrew Handwriting Evaluation* (HHE; Erez & Parush, 1999), which is a standardized test evaluating handwriting speed and legibility, under two conditions: copying and dictation using two separate texts. In this study only the copying scores were analyzed. Interrater reliability for the HHE is $r = .75–.79$, $p < .001$. Construct validity was established by comparing the performance of proficient and poor handwriters on the HHE. Results indicated statistically significant differences ($t = -2.34$, $p = .027$) between the groups.

Keyboarding ability was evaluated by having the students copy-type a paragraph into the computer. In both handwriting and in keyboarding the copied paragraphs consisted of 270 characters, including letters, punctuation marks, and spaces. These paragraphs were taken from 5th-grader's textbooks. For both tasks, two measures were calculated: (a) *percent accuracy,* which was calculated by counting the number of letters or characters the students wrote or typed minus the writing or typing errors (i.e., addition, deletions, and substitutions) divided by the overall number of characters written or typed and multiplied by 100 and (b) *speed*, which was defined as the number of letters–characters written–typed per minute.

Procedure

Pretesting

Prior to the commencement of touch-typing training, the above-described performance components measures were administered individually to each study participant. In addition, initial keyboarding skills were evaluated. None of the students knew how to touch-type.

Touch-Typing Instruction

Students were divided into six groups of about 10 students each. The lessons took place in the computer classroom at the participants' school. Students were seated on chairs suitable for their height, in front of an individual desktop computer running the Windows 95 operating system, with the monitor positioned at eye level. A standard 102 key keyboard was used. Each student attended a series of fifteen 20-minute lessons, two lessons per week for a total of 5 hours. The lessons and the typing tests were delivered via a touch-typing tutorial program entitled "Touch-Typing Now" (TES, Inc., 2003).

Posttesting

Following the touch-typing training, keyboarding and handwriting performance were reevaluated.

Data Analysis

Although students' keyboarding performance was measured both prior to and following keyboarding instruction, analysis of the results are based on the posttest scores only. The rationale for this is that the purpose of this study was to examine various factors that are related or contribute to performance of students who acquired touch-typing keyboarding skills (versus "hunt and peck" unskilled keyboarding). First, descriptive statistics were employed in order to describe students' handwriting and keyboarding percent accuracy and speed. Next, Pearson correlations were used to examine the relationship between handwriting and keyboarding percent accuracy and speed. In order to examine the relationship between performance components and handwriting and keyboarding skills, Pearson or Spearman correlations were performed (according to type of scores). Finally, multiple regression analyses were administered with the purpose of examining the contribution of the various performance components to handwriting and keyboarding percent accuracy and speed.

Results

We first looked at students' handwriting and keyboarding skills with the purpose examining if students' keyboarding performance was at least as good as their handwriting. Results indicated that the students' percent-accuracy for both handwriting and keyboarding was greater than 90%. In contrast, students were much slower while keyboarding than while handwriting; they hand-wrote almost double the number of letters per minute (80.7) compared to the number of characters they typed per minute (48.4).

Next, we examined the correlation between handwriting and keyboarding percent-accuracy and speed. Results indicated there was no statistically significant correlation between handwriting and keyboarding percent-accuracy ($N = 47$, $r = .05$, $p = .73$), but there was a moderate and significant correlation between handwriting and keyboarding speeds ($N = 52$, $r = .34$, $p = .012$). These correlations indicate that handwriting speed accounted for 14% of the variability in keyboarding speed. Pearson or Spearman correlation analyses were then performed in order to examine the correlation between the underlying performance components and handwriting and keyboarding percent-accuracy and speed. As shown in Table 2, only Finger Lifting was significantly correlated with *both* handwriting and keyboarding percent-accuracy. The VMI and Left-Right Discrimination were correlated only with *handwriting* percent-accuracy, whereas Alternating Fists as well as two other components measuring memory functions (i.e., Visual Recognition and Recall of Complex Finger Opposition)

Table 2. Correlation Between Performance Components and Handwriting and Keyboarding Percent-Accuracy and Speed.

Performance Components	Percent-Accuracy		Speed	
	Handwriting	Keyboarding	Handwriting	Keyboarding
Finger Lifting	.31*	.32*	.24	.06
Finger Recognition	.00	.12	.28*	.27*
Visual Motor Integration	.27*	.16	.12	-.05
Visual Perception	.13	.18	.38**	.24
Motor Coordination	.24	.10	.31*	-.12
Lt.-Rt. Discrimination (on examiner)	.33**	.21	.17	.24
Alternating Fists	.16	.35*	.09	.20
Complex Finger Opposition	.14	-.01	.20	.33*
Pencil Speed	.12	.24	.05	.13
Pencil Excursion	-.03	-.24	-.23	-.27*
Visual Recognition	.09	.30*	-.02	.07
Visual Retrieval	.20	.09	.23	.24
Recall Complex Finger Opposition	.17	.33*	.15	.24
DEM horizontal	-.11	-.13	-.39**	-.55**
DEM vertical	-.05	-.16	-.17	-.30*

Note. * $p < .05$.; ** $p < .01$.

were significantly correlated only with *keyboarding* accuracy. Not surprisingly, different performance components correlated with handwriting and keyboarding speed although there was some overlap. Thus, the two components that significantly correlated with both handwriting and keyboarding speed were the DEM (horizontal) and Finger Recognition. In contrast, the Visual Perception and Motor Coordination tests were significantly correlated only with handwriting speed and Complex Finger Opposition and Pencil Excursion (both measuring kinesthetic ability) as well as the DEM (vertical) were significantly correlated only with keyboarding speed.

Separate multiple regression analyses were performed in order to examine the contribution of various performance components to handwriting and keyboarding percent-accuracy. In these analyses, only those components significantly correlated with the dependent variables were entered into the regression models. In the first model, handwriting percent-accuracy served as the dependent variable. Gender was included in the model because most studies have found this variable to be a significant predictor of handwriting performance (Graham & Weintraub, 1996). Results indicated that only Left-Right Discrimination had a significant contribution to handwriting percent-accuracy beyond the contribution of the other variables in the model (t = 2.60, p = .012) and that together, the components explained 24.5% of the variance in percent-accuracy of handwriting.

Similarly, multiple regression analysis was performed with keyboarding percent-accuracy serving as the dependent variable. Different components were entered into the regression model, in the manner described above for handwriting percent-accuracy. None of the components had a unique and significant contribution, and explained only 5.9% of the variance in keyboarding percent-accuracy.

Finally, in order to examine the contribution of the performance components in predicting handwriting and keyboarding speed, a multiple regression analysis was carried out. Only those components that were significantly correlated with the dependent variables were entered into the regression models. In the first model, *handwriting* speed served as the dependent variable. Here, too, gender was included in the handwriting model. The DEM-horizontal was the only significant predictor of handwriting and keyboarding speed (t = -2.33, p = .024; t = -3.18, p = .003, respectively). Together the models explained 22.1% of the variance in handwriting speed and 30.2% in keyboarding speed.

The regression models described above served to examine whether the performance in handwriting and keyboarding speed may be explained by shared performance components. That is, can the moderate and significant correlation that was found between these skills be explained by the fact that similar components predicted performance in these skills? From a clinical point of view, the rationale for such an analysis was that if students with deficits in specific performance components (related to handwriting skills) are writing slowly, and if these components also predict keyboarding speed, then perhaps these students would also have difficulty mastering keyboarding skills. If this were the case, compensatory approaches other than keyboarding should be employed for assisting children with handwriting difficulties.

However, in analyzing the data, this study's results showed that, as opposed to keyboarding percent-accuracy, students' keyboarding speed prior to instruction (hunt and peck) significantly correlated with keyboarding speed after instruction (r = .67, p = .000). These findings brought to mind the possibility that as in the case of the specific performance components, initial keyboarding speed may also serve as a significant factor in predicting students keyboarding speed following instruction. Therefore, it appeared essential to include preinstruction keyboarding speed into the regression model together with the same dependent variables, with keyboarding speed serving as the dependent variable. Thus, an additional multiple regression analysis was carried out. Results of this regression analysis show that initial keyboarding speed and the DEM-horizontal were the only significant predictors of keyboarding speed (t = 4.147, p = .000; t = -2.037, p = .048, respectively). The addition of initial keyboarding speed to the regression model increased significantly the percent of variance in keyboarding speed explained by these variables (adjusted R^2 = 48.3%, as compared to 30.2% in the previous analysis).

Discussion

The results of this study showed that students' accuracy while handwriting and keyboarding was quite high (greater than 90%). In contrast, there were considerable differences in speed when they wrote as compared to when they typed. Since the participants in this study were in the 5th grade, it was not surprising that the students had such good scores for handwriting percent-accuracy and speed since at this level, handwriting is usually automatic (Levine, 1987). The disparity in keyboarding accuracy as compared to keyboarding speed may be explained, in part, by the fact that the keyboarding instruction emphasized accuracy rather than speed, and that the students received only 5 hours of keyboarding instruction. It is thus reasonable to assume that they were still at the initial stages of touch-typing acquisition, (i.e., the cognitive and associative phases)

(Sormunen, 1993), and that the postinstruction keyboarding speed scores achieved in this study do not reflect their optimal keyboarding abilities. It is likely that the attainment of keyboarding speed comparable to handwriting speed will require significantly longer periods of instruction and practice.

The results of this study also showed that there was no significant correlation between handwriting and keyboarding percent-accuracy. With regard to the underlying performance components, Finger Lifting, requiring tactile perception and kinesthetic ability, correlated with both handwriting and keyboarding percent-accuracy scores. However, in general, different components correlated with each task. Whereas Visual Motor Integration and Spatial Perception scores significantly correlated with percent-accuracy while handwriting, measures of bilateral coordination as well as motor and visual memory functions significantly correlated with keyboarding percent-accuracy.

These findings would appear to suggest that handwriting and keyboarding accuracy require different abilities. Keyboarding requires the memorization of a large number of associations between spatial locations and verbal codes (Gopher & Raij, 1988), the positioning of the fingers on these locations and then the pressing of each key with great precision and timing (Cooper, 1982). Handwriting, on the other hand, requires the matching of a motor program for the formation of a specific allograph and then executing this program (van Galen, 1991). Handwriting also involves spatial organization abilities, which are not necessary while keyboarding. It is thus apparent that the requirements for accuracy while writing may differ from those while keyboarding.

Further, with respect to handwriting, accuracy requires primarily linguistic and perceptual-cognitive functions. In contrast, for keyboarding, even if the students remembered and retrieved the letters correctly, they still needed to decide which digit of which hand to place on specific keys in order to type the necessary letters in highly coordinated, rapid-movement sequences (Gopher & Raij, 1988). This intricate and synchronized process may explain this study's findings in which bilateral coordination, kinesthetic ability, and memory functions were found to be significantly correlated with keyboarding accuracy.

In contrast to the findings for accuracy, the results of this study indicated that handwriting and keyboarding speed were moderately and significantly correlated. These results are similar to those by Kahn and Freyd (1990) and by Rogers and Case-Smith (2002). It is interesting to note that these studies were conducted in different countries and in different languages (Hebrew and English) among children with similar ages and typing experience.

In analyzing the performance components that correlate with each of these skills it appears that tactile perception, and oculo-motor movement abilities (i.e., the DEM-horizontal) were significantly correlated with both handwriting and keyboarding speed. Handwriting speed was also significantly correlated with visual-perception and motor-coordination abilities, whereas keyboarding speed was significantly correlated with kinesthetic abilities. Taking into account the requirement of the keyboarding test, namely, copying a paragraph via keyboarding, it is possible that students' reading time influenced these results, thus indicating that the DEM is related to the initial part of the copying task (reading speed) rather than to output aspects of copying (i.e., handwriting or keyboarding). This possibility could be examined in a future study by dictating a paragraph to students rather than have them copying it.

The results of this study, however, showed that a significant factor that contributed to the prediction of keyboarding speed, following touch-typing instruction, was students' initial keyboarding speed. When initial keyboarding speed was included, the regression model explained 48.3% of the variance in keyboarding speed as compared to 30.2%, when only performance components were included. These results bring several questions to mind. Are the basic skills required for "hunt and peck" keyboarding similar to the skills necessary for touch-typing? Or, perhaps students were still not at the stage of proficient touch-typing and therefore there was significant correlation between these skills. Another possibility is that the measure of keyboarding speed was based on a copying task and perhaps here, too, the speed of reading influenced both measurements. It is clear that these issues should be further examined.

It is interesting to note that, in the multiple regression analyses of the performance components on handwriting percent-accuracy and speed, gender did not significantly contribute to the prediction of handwriting performance above and beyond the contribution of other components in the regression models. This finding is in contrast to the results of other studies, which found gender differences in handwriting performance (for a review see Graham & Weintraub, 1996), but similar to those found in a study of children in the same age group (Weintraub & Graham, 2000). A possible explanation for the disparity in the findings is the type of statistical analyses performed in the different studies. Gender differences were reported mostly when the studies compared the handwriting performance of boys and girls. In contrast, in this study and in the study by Weintraub and Graham, the contribution of gender in predicting handwriting performance was examined in a regression model together with several other components that were found to significantly correlate with handwriting performance. Thus, the possible contribution of gender may have been overshadowed by the effect of other components that were in the model, and so it appears that gender is a factor that has to be taken into account (or controlled for) when examining handwriting performance, but when other factors are considered, simultaneously, its contribution in predicting handwriting performance is relatively small.

Conclusions

It appears that keyboarding may be a potential alternative tool for written communication for students with handwriting difficulties (especially when accuracy is an issue). Yet, it also seems that when speed is the issue, handwriting and initial keyboarding speed should be taken into account when trying to decide if a student could benefit from keyboarding.

However, these findings should be considered with caution, due to the fact that this study is one of the first on this topic; additional data are necessary both to replicate these findings and to further identify the underlying performance components related to keyboarding. Moreover, in order to demonstrate that these findings can be generalized to other populations, it must be remembered that the students in this study had just completed the initial stage of touch-typing acquisition, and their keyboarding skills were most likely at a cognitive rather than at an automatic level. It is important to examine whether the components that were significantly correlated with keyboarding speed and accuracy of the students in their initial stages of keyboarding are also related to keyboarding performance of skilled typists, which is the stage at which we expect students to perform once they have acquired this skill. Moreover, although the sample in this study included children with handwriting difficulties, most students were proficient handwriters. It is, therefore, important to determine if similar relationships between performance components and handwriting and keyboarding skills would also be found among children who have handwriting difficulties.

As stated by Jones Loheyde (1984), we must remember, that "improvement in any skill does not come about merely by changing the medium on which it is done" (p. 85). In other words, having students use keyboards rather than pen and pencils for writing will not necessarily solve their writing difficulties. If occupational therapists are to assist students with handwriting difficulties to master keyboarding skills, and use them efficiently while writing, continued effort must be made to further study these issues. ▲

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References

Abbott, R. D., & Berninger, V. W. (1993). Structural equation modeling of relationships among developmental skills and writing skills in primary- and intermediate-grade writers. *Journal of Educational Psychology, 85,* 478–508.

Balajthy, E. (1988). Keyboarding, language arts, and the elementary school child. *The Computing Teacher, 15*(5), 40–43.

Beery, K. E. (1997). *Developmental Test of Visual Motor Integration (VMI): Administration, scoring and teaching manual* (4th ed.). Cleveland, OH: Modern Curriculum Press.

Berninger, V. W., & Rutberg, J. (1992). Relationship of finger function to beginning writing: Application to diagnosis of writing disabilities. *Developmental Medicine and Child Neurology, 34,* 198–215.

Cooper, W. E. (1982). Introduction. In W. E. Cooper (Ed.), *Cognitive aspects of skilled typewriting* (pp. 1–38). New York: Springer-Verlag.

Cornhill, H., & Case-Smith, J. (1996). Factors that relate to good and poor handwriting. *American Journal of Occupational Therapy, 50,* 732–739.

Denckla, M. B. (1974). Development of motor co-ordination in normal children. *Developmental Medicine and Child Neurology, 16,* 729–741.

Erez, N., & Parush, S. (1999). *The Hebrew Handwriting Evaluation (HHE).* Jerusalem, Israel: Hebrew University, Faculty of Medicine, School of Occupational Therapy.

French, S., Reynolds, F., & Swain, J. (2001). *Practical research: A guide for therapists* (2nd ed.). Boston: Butterworth Heinemann.

Garzia, R. P., Richman, J. E., Nicholson, S. B., & Gaines, C. S. (1990). A new visual-verbal saccade test: The Developmental Eye Movement test (DEM). *Journal of the American Optometric Association, 61,* 124–134.

Gopher, D., & Raij, D. (1988). Typing with a two-hand chord keyboard: Will the QWERTY become obsolete? *IEEE Transactions on Systems, Man and Cybernetics, 18,* 601–609.

Graham, S., & MacArthur, C. (1988). Improving learning disabled students' skills at revising essays produced on a word processor: Self instructional strategy training. *The Journal of Special Education, 22,* 133–153.

Graham, S., & Weintraub, N. (1996). A review of handwriting research: Progress and prospects from 1980 to 1994. *Educational Psychology Review, 8,* 8–87.

Hamstra-Bletz, L., & Blote, A. W. (1993). A longitudinal study on dysgraphic handwriting in primary school. *Journal of Leaning Disabilities, 26,* 689–699.

Jones, I. (1994). The effect of word processor on the written composition of second-grade pupils. *Computers in the Schools, 11*(2), 43–54.

Jones-Loheyde, K. M. (1984). Computer use in the teaching of composition: Considerations for teachers of writing. *Computers in the Schools, 1*(2), 81–86.

Kahn, J., & Freyd, P. (1990). Touch typing for young children: Help or hindrance? *Educational Technology, 30*(2), 41–45.

Koorland, M. A., Edwards, B. J., & Doak, P. (1996). Evaluating a systematic keyboarding strategy for students with learning disabilities. *Computers in the Schools, 12*(3), 13–20.

Law, M., Baum, C. M., & Baptiste, S. (2002). *Occupation-based practice: Fostering performance and participation.* Thorofare, NJ: Slack.

Levine, M. D. (1984). *Pediatric examination of educational readiness at middle school.* Cambridge, MA: Educators Publishing Services.

Levine, M. D. (1987). *Developmental variations and learning disorders.* Toronto, Ontario, Canada: Educators Publishing Services.

MacArthur, C. (1998, Spring). Assistive technology for writing. *Perspectives,* 16–18.

MacArthur, C. A., & Shneiderman, B. (1986). Learning disabled students' difficulties in learning to use a word-processor: Implications for instruction and software evaluation. *Journal of Learning Disabilities, 19,* 248–253.

Margalit, M., & Roth, Y. B. (1989). Strategic keyboard training and spelling improvement among children with learning disabilities and mental retardation. *Educational Psychology, 9,* 321–329.

Mayer Nichols, L. (1996). Pencil and paper versus word processing: A comparative study of creative writing in the elementary school. *Journal of Research on Computing Education, 29,* 159–166.

McClurg, P., & Kercher, L. (1989). Keyboarding instruction: A comparison of five approaches. *Journal of Computing Research, 5*(4), 447–458.

Neufeld, K. (1989). When children use word processors for writing: Some problems and suggestions. *Reading Improvement, 26,* 64–70.

Penso, D. E. (1999). *Keyboarding skills for children with disabilities.* London: Whurr Publishers.

Phelps, J., Stempel, L., & Speck, G. (1985). The Children's Handwriting Scale: A new diagnostic tool. *Journal of Educational Research, 79,* 46–50.

Rogers, J., & Case-Smith, J. (2002). Relationship between handwriting and keyboarding performance of sixth-grade students. *American Journal of Occupational Therapy, 56,* 34–39.

Rubin, N., & Henderson, S. E. (1982). Two sides of the same coin: Variation in teaching methods and failure to learn to write. *Special Education: Forward Trends, 9*(4), 17–24.

Sandler, A. D., Watson, T. E., Footo, M., Levine, M. D., Coleman, W. L., & Hooper, S. R. (1992). Neurodevelopmental study of writing disorders in middle childhood. *Developmental and Behavioral Pediatrics, 13*(1), 17–23.

Sormunen, C. (1988). A comparison of speed achievement of students in grades 3–6 who learn keyboarding on the microcomputer. *The Delta Pi Epsilon Journal, 30*(2), 47–57.

Sormunen, C. (1993). Learning style: An analysis of factors affecting keyboarding achievement of elementary school students. *The Delta Pi Epsilon Journal, 35*(1), 26–38.

TES, Inc. (2003). Touch Typing Now. www.jewishsoftware.com

Tseng, M. H., & Chow, S. M. K. (2000). Perceptual-motor function of school-age children with slow handwriting speed. *American Journal of Occupational Therapy, 54,* 83–88.

Tseng, M. H., & Murray, E. A. (1994). Differences in perceptual motor measures in children with good and poor handwriting. *Occupational Therapy Journal of Research, 14*(1), 19–36.

van Galen, G. P. (1991). Handwriting: Issues for a psychomotor theory. *Human Movement Science, 10,* 165–191.

Waner, K., Behymer, J., & McCrary, S. (1992). Two points of view on elementary school keyboarding. *Business Education Forum, 47,* 27–29.

Weintraub, N., & Graham, S. (2000). The contribution of gender, orthographic, finger function, and visual-motor processes to the prediction of handwriting status. *Occupational Therapy Journal of Research, 20,* 121–140.

Yinon, M., & Weintraub, N. (2000). Intervention programs for improving handwriting performance: A review. *Israel Journal of Occupational Therapy, 9*(1), H17–H35.

Yochman, A., & Parush, S. (1998). Differences in Hebrew handwriting skills between Israeli children in second and third grade. *Physical & Occupational Therapy in Pediatrics, 18,* 53–65.