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Abstract Legible written communication is essential for students to share knowledge (Rogers and Case-Smith 2002). If students lack proficiency in written communication, their composition skills will suffer, which can affect their self-esteem and grades. Whether or not this proficiency is in handwriting or keyboarding is a question worthy of discussion. In this article the authors define motor learning, examine the overlapping principles of motor learning in handwriting and keyboarding skill development, and discuss the need for fluency. The principles of motor learning indicate that handwriting precedes keyboarding when comparing skills and time needed to gain competency. Also discussed are correlations between handwriting and keyboarding skills and the impact of teacher attitudes toward each. As occupational therapists, the authors' recommendations are based on the review of literature and evidence their combined with their extensive experience as school-based occupational therapists. Using a school-based consultative model of occupational therapy at the continuing education or university educational level can facilitate the sharing of this knowledge with early childhood education teachers.

Keywords Handwriting · Keyboarding · Consultative model of occupational therapy

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Introduction

Do students need to be proficient in handwriting, when they will ultimately rely on keyboarding for written communication? Whether handwriting or keyboarding, students need to have some form of fluent written communication (Connelly et al. 2007) to express what they know (Amundson and Weil 1996; Rogers and Case-Smith 2002).

There is little research on the effectiveness of the word processor on enhancing composition skills (Connelly et al. 2007), although fluent handwriting and good spelling (Connelly et al. 2007; Graham 2009) have been shown to improve the quality of a student's composition skills (Amundson and Weil 1996; Christensen 2005; Graham 2009). Our working memory, unlike long-term memory which can store memories for years, is limited in the quantity of information and the time it can hold this information to carry out tasks (Medwell and Wray 2008). To adults, writing a letter of the alphabet seems automatic because they have developed kinesthesia/motor memory to create the letter, but for children, this can be challenging and require great concentration (Massengill Shaw 2011). If working memory is needed for lower level tasks of handwriting or finding keys on a keyboard then students will be limited in their ability to engage in the many aspects of writing: idea creation, vocabulary selection, composition and revision (Freeman et al. 2005; Medwell and Wray 2008). Students with fluent handwriting reinforce their composition skills through practice; however, students lacking fluency have little opportunity to make progress with their composition skills, and can suffer motivationally (Graham 2009; Medwell and Wray 2008; Parush et al. 1998). This in turn affects their grades (Graham 2009; Parush et al. 1998).

Children with illegible handwriting are often referred to occupational therapy (OT) (Benbow 1995). Occupational

therapists (OTs) are able to determine in what area of handwriting a student is having difficulty: near or far point copying, dictation, environmental factors, or motor, sensory, psychosocial or cognitive factors (Amundson and Weil 1996). Traditionally, an OT will provide direct service using a 'pull out' model, working on specific Individual Education Program (IEP) goals (Hanft and Place 1996) to address the deficits identified (Amundson and Weil 1996). In the 1990s the consultative model was introduced to school-based OT practice (Hanft and Place 1996; Reid et al. 2006; Wehrmann et al. 2005). This model promotes both formal and informal sharing of ideas and strategies with the teacher supporting the student's goals (Barnes and Turner 2001; Hanft and Place 1996). Teachers using OT strategies in the classroom can enhance student success (Barnes and Turner 2001; Hanft and Place 1996; Reid et al. 2006; Wehrmann et al. 2005).

With the increased availability of computers in the classroom, when students have illegible handwriting, the question often arises regarding keyboard use as an alternative to handwriting (Rogers and Case-Smith 2002). Computer use varies from school to school with an assortment of applications; however, there is little evidence to support the varied use (Freeman et al. 2005). Some general conclusions about keyboarding skills can be drawn with regard to speed, accuracy, use of touch-keyboarding technique, and the need for instruction and practice to gain competency (Freeman et al. 2005).

Keyboarding can serve as an alternative to handwriting for children having fluency issues; however it is important to recognize that there are few guidelines for keyboarding (Rogers and Case-Smith 2002). For example, determining norms for keyboarding speed at various grade/age levels is difficult since instructional levels needed to achieve targeted speeds is unknown (Freeman et al. 2005). If a child is not fluent in keyboarding, (s)he may be concentrating on key location rather than composition (Connelly et al. 2007; Freeman et al. 2005), similar to focusing on letter formation with handwriting. To be an effective alternative to handwriting, keyboarding speeds need to be at least as fast as handwriting (Freeman et al. 2005). A focus on motor learning in the development of hand skills is helpful in understanding how students acquire handwriting and keyboarding skills. Handwriting and keyboarding skill development share common features, yet each requires unique abilities while playing a role in literacy and composition skill development.

Commonalities Between Handwriting and Keyboarding

When composition skills are emphasized, students receive better grades if they are fluent in handwriting or keyboarding (Connelly et al. 2007). Looking at each skill, it is helpful to note their commonalities.

To gain skill in either handwriting or keyboarding, the student must have motor competence (Connelly et al. 2007; Freeman et al. 2005; Rogers and Case-Smith 2002). Handwriting involves complex motor learning, including the integration of visual-perceptual and fine motor skills with cognition (Exner 1989). With keyboarding, although there is motor learning, it is less complex initially, as students make linear finger movements to specific keys rather than letter strokes (Chwirka et al. 2002). However, as keyboarding skills progress, the strokes are serial and in rapid succession, increasing the complexity of the motor task (Freeman et al. 2005). Additionally, both handwriting and keyboarding require a child to receive feedback from sensory systems of touch, kinesthesia/motor memory and vision. In handwriting, the sense of touch and positioning provides information about how one is holding the pencil, and positioning the paper (Cunningham Amundson 1992). Kinesthesia/motor memory refers to the refinement of the finger/pencil movement during handwriting, pencil pressure and direction of movement (Cornhill and Case-Smith 1996; Cunningham Amundson 1992). Initially, handwriting requires visual control for guidance of the pencil (Benbow 1995). Keyboarding initially requires visual guidance and feedback in locating keys, and in copying text (Freeman et al. 2005; Longcamp et al. 2005). As a student's skills increase in both handwriting and keyboarding, kinesthesia/motor memory takes over for vision, as fingers "remember" how to print letters or locate commonly used keys (Freeman et al. 2005). But how does one gain motor skill competence?

The Development of Motor Skills

An early example of motor learning is seen as infants and toddlers attain their developmental milestones. These milestones have an age range when movements become refined and effective, in relation to task and any external forces, such as gravity (Kamm et al. 1990). When the body moves in response to a task, the brain perceives and integrates information in a non-linear fashion of self-organization (Kamm et al. 1990; Thelen 1995), automatically resulting in the easiest motor movement for the task (Kamm et al. 1990). This suggests that small changes in a task potentially can have a large impact on performance (Thelen 1995). With motor learning, skills adapt in response to the objects/tools utilized (Smith-Zuzovsky and Exner 2004). For both handwriting and keyboarding these tools include the desk/chair, pencil/paper or keyboard.

The Ergonomics of Handwriting and Keyboarding

Ergonomics, defined as using tools that fit a person while he or she participates in a task, facilitate motor skill

development (Smith-Zuzovsky and Exner 2004). Ergonomics are usually thought of with respect to adults. However, the concept of proper positioning enhancing adult work production, while decreasing the chance of injury, also applies to children (Yeats 1997). For example, to fit a child, the chair needs to allow for a 90° angle at the hips, with the feet on a flat surface, while leaning against a backrest (American Occupational Therapy Association (AOTA) 2001; Benbow 1995; Cunningham Amundson 1992; Smith-Zuzovsky and Exner 2004). The classroom desk needs to be approximately one inch above a child's bent elbow (AOTA 2001; Benbow 1995; Cunningham Amundson 1992; Smith-Zuzovsky and Exner 2004). If a desk is too high, a child's arm is positioned too far from the body for good control of his or her fingers (Benbow 1995). Most computer work stations and equipment are created for adults (AOTA 2001). It is important to create a good sitting position by placing a footrest under a child's feet, and either raising the chair, or providing cushions to position a child so their forearms are parallel to the keyboard, while held slightly above the keyboard (AOTA 2001). The monitor height should be level with one's head, with the top of the screen at eye level, 18–30 inches from the child (AOTA 2001). Principles of ergonomics apply equally to handwriting and keyboarding in preventing injury and maximizing performance.

Stages of Motor Learning

Appropriately sized equipment (desks/tables/chairs and crayons/pencils) facilitates students' participation in motor learning for either handwriting or keyboarding. The three stages of motor learning for handwriting and keyboarding are similar, yet occur at different times (Table 1). Each begins by using cognition and vision, progresses to developing motor performance, and finally to developing fluency through kinesthesia/muscle memory and self-monitoring (Benbow 1995; Guadagnoli and Lee 2004; Poole 1991; Ste-Marie et al. 2004). Meaningful practice supplemented by dynamic motor and cognitive variables challenge a student towards fluency (Guadagnoli and Lee 2004; Poole 1991; Ste-Marie et al. 2004).

Table 1 Handwriting and keyboarding stages of motor learning

Motor learning stage	Handwriting	Keyboarding
1st	5 years	10–12 years
Involves cognition and use of vision[a,b,c,d]	Teacher identifies letter, and describes formation strokes as demonstrates stroke sequence[e,f], then student imitates letter[a,b,c,d]	Participates in touch keyboarding instruction[g] Identifies the letter and locating it on the keyboard[g]
2nd	5–6 years	10–12 years
Developing motor performance[a,b,c,d]	Tracing letters with verbal stroke sequence and visual cues. Verbal cueing fades as gains mastery[e,f] Motor and cognitive challenges increase as abilities develop[b,c,d] Meaningful practice to support skill development[e]	Uses home keys of touch keyboarding[g] Locates letters from home keys, using good technique[g] Develops of muscle memory for finger excursions to related keys[g]
3rd	6–7 years	10–12 years
Gradual improvement to automatic fluency[a,b,c,d]	Gradual improvement until handwriting fluent and automatic, embedded in kinesthesia/motor memory Teacher provides feedback supporting students in self-monitoring[a,b,c,d,f] 7 + years Development of speed[a] Continue meaningful practice to support skill development[e]	Shows gradual improvement in kinesthesia/muscle memory for locating keys[g] Uses vision to locate less frequently used keys and to check for errors[g] Increases speed with daily, meaningful practice opportunities[g] Needs to gain speed greater than handwriting speed in order to be functional[g]

[a] Benbow (1995)

[b] Guadagnoli and Lee (2004)

[c] Poole (1991)

[d] Ste-Marie et al. (2004)

[e] Amundson and Weil (1996)

[f] Cunningham Amundson (1992)

[g] Freeman et al. (2005)

The Significance of Speed

In handwriting, speed is part of motor learning (Benbow 1995) and can impact legibility (Cunningham Amundson 1992; Naider-Steinhart and Katz-Leurer 2007; Peterson and Nelson 2003). Before introducing speed, it is important to over-learn the foundational skills through meaningful practice (Cunningham Amundson 1992; Peterson and Nelson 2003) (See Table 1). For keyboarding to be functional, a student's keyboarding speed needs to be at least as fast as a student's handwriting, or faster (Connelly et al. 2007; Freeman et al. 2005). As the kinesthesia increases, with students knowing the trajectory needed to access keys and the sequencing to type a word, they can begin working to increase their speed (Freeman et al. 2005). Students who learned to keyboard quickly used keyboarding daily for meaningful assignments (Freeman et al. 2005). Meaningful practice is a key for fluency in both keyboarding and handwriting.

There is a low to moderate correlation between handwriting speed and legibility to keyboarding speed (Rogers and Case-Smith 2002). Children who have good handwriting often will have good competence and speed when keyboarding; those with fairly poor handwriting may be more effective keyboarders, providing they have some level of keyboarding instruction to develop competence (Rogers and Case-Smith 2002). Freeman et al. (2005) have found a fair to moderate correlation between the acquisition of keyboarding skills and keyboarding speed with handwriting speed (Freeman et al. 2005). The correlations suggest good fine motor skills for handwriting facilitate keyboarding both in acquiring skills and speed (Freeman et al. 2005), inter-relating the motor learning of handwriting skills to keyboarding skills.

The Need for Structured Instruction

To facilitate motor learning and skill acquisition, there are varying opinions about formal structured instruction as opposed to informal, teachable moments. Research supports precise handwriting instruction (Asher 2006; Graham 2009; Olsen and Knapton 2008). Teachable moments can be used to reinforce structured instruction (Graham 2009). Providing students with meaningful activities to practice will promote fluency (Cunningham Amundson 1992; Peterson and Nelson 2003). With keyboarding, opinions again differ on structured instruction versus informal learning; however, there is general consensus that keyboarding instruction increases competence (Freeman et al. 2005). This instruction can be enhanced with ongoing less formal, meaningful practice (Freeman et al. 2005).

Handwriting is one of the first things we learn in school, and we use it our entire lives (Parush et al. 1998). In spite of this, little attention is paid to when, where, or how students develop these skills (Benbow 1995). In grades 1–3, the recommendation of structured handwriting instruction is 50–100 min per week, either daily or several times a week, devoted to achieving mastery (Graham 2009). Students need enough structured handwriting instruction so they can develop the kinesthesia/motor memory to remember the stroke sequence for letter formation from one lesson to the next (Asher 2006). It is important to assist students in developing good habits early (Amundson and Weil 1996; Benbow 1995), beginning with preschool activities (Amundson and Weil 1996; Benbow 1995). To facilitate kinesthesia/muscle memory of forming letters, it is recommended that a school use a consistent handwriting curriculum throughout the grades, as each curriculum uses unique descriptions for letter formation. If curricula change, letter formations also change, thereby requiring new motor learning, which can be difficult for some students (Asher 2006). Even with consistent curricula, most program emphasize form over fluency (Massengill Shaw 2011).

In the United Kingdom (UK), keyboarding is not a required subject (Connelly et al. 2007). Connelly et al. (2007) compared handwriting competence to keyboarding competence of students from the UK, ages 4–11, and found the compositional quality of handwritten text superior to that produced with keyboarding. The students' handwriting competency skills were 1.5–2 years higher than their keyboarding skills due to lack of structured keyboarding instruction (Connelly et al. 2007). Rogers and Case-Smith (2002) found when 6th grade students had a 12 week formal keyboarding instruction program they could keyboard a mean of 5 words per minute more than they could handwrite (Rogers and Case-Smith 2002), suggesting structured keyboarding instruction at this age produced more words per minute than handwriting. There is little evidence supporting touch-keyboarding over 'hunt and peck', but it makes sense that learning touch-keyboarding would be more efficient, as this skill depends more on kinesthesia than vision (Freeman et al. 2005). The general agreement is that good technique is preferred, and touch-keyboarding is associated with the achievement of target keyboarding speeds (Freeman et al. 2005). Again forming the good habit of learning touch-keyboarding from the outset facilitates fluency (Freeman et al. 2005).

When to Teach What

Age appropriate expectations are essential to ensure success in the motor learning process of either handwriting or keyboarding skills. Preschool is an ideal time to work with developmentally sequenced fine motor activities, enhancing the foundation of these fine motor skills (Benbow 1995). Developmentally speaking, a child first imitates and then copies both lines and shapes; these skills are needed before introducing letter formation (Amundson and Weil

1996; Berry and Berry 2004). When children feel their handwriting is poor, this is reinforced each time they write, which can contribute to poor motivation toward writing tasks. Working for success is paramount (Amundson and Weil 1996; Cunningham Amundson 1992).

By 6–7 years of age, most students are fairly fluent in writing (Amundson and Weil 1996; Berry and Berry 2004). It is important to look at the feasibility of keyboarding skill development and the implications for when instruction can and should be provided (Freeman et al. 2005). Second graders participating in a keyboarding program, 15 min a day for 8 months achieved competency of five words per minute, roughly equivalent to grade level handwriting of four to six words per minute (Chwirka et al. 2002). In comparison, sixth graders participating in thirty 40 min sessions of keyboarding instruction over 12 weeks were found to have mean keyboarding speed 5 words per minute faster than their mean handwriting speed (Rogers and Case-Smith 2002). Comparing these studies suggests it might be more effective to wait until students are 10–12 years old to begin keyboarding instruction, as they gain skills more quickly, producing more letters per minute than with handwriting. A literature review suggests that an appropriate time to begin teaching keyboarding is in the upper elementary grades as it takes students less time to develop competency (Freeman et al. 2005).

Advantages of Handwriting

There is evidence suggesting letter memorization is linked to learning handwriting (Mangen and Velay 2010). Effective instruction in early handwritten letter formation includes verbal instructions for stroke sequence and directing the motor movement with visual cueing (Amundson and Weil 1996; Benbow 1995; Cunningham Amundson 1992). This stroke sequencing has been found to help with reading impairments (Longcamp et al. 2005). Longcamp et al. (2005) found handwriting more effective in memorizing letter shapes than keyboarding with children age 4 years—5 months, as the key stroke was not associated with a visual representation of a letter. Identifying a keyboard letter requires visual discrimination between letter forms, whereas the motor learning in letter formation assists with identifying letter shapes. This study could not determine the impact on a child's ability to read words, as the children were pre-reading, but letter recognition is recognized as a precursor to reading (Longcamp et al. 2005).

Advantages to Keyboarding

Handwriting legibility is rated by letter formation, letter spacing within and between words, letter size, alignment and slant consistency (Cunningham Amundson 1992; Peterson and Nelson 2003). As workloads increase, students often have to choose between speed and legibility. To have their work legible, they may not complete the assignment within the allotted time; to be time efficient, their assignment may be illegible (Freeman et al. 2005). With keyboarding, however, errors have less to do with letter legibility. They include additional or lack of spacing and/or typing the wrong letters (Rogers and Case-Smith 2002). Only when there are a large number of errors will the overall legibility of keyboarding be effected (Freeman et al. 2005).

Rogers and Case-Smith (2002) compared 6th graders' handwriting speed and legibility with keyboarding speed and error rate, after they had completed thirty 40 min sessions of keyboarding instruction over 12 weeks. They found one quarter to one third of the students with slow handwriting speed and low legibility achieved more text production with keyboarding. This study suggests students with poor handwriting could be more effective keyboarders (Rogers and Case-Smith 2002), allowing them to concentrate on content, once they have gained some keyboarding proficiency (Rogers and Case-Smith 2002).

Teacher Knowledge

Although the background of motor learning and benefits of both handwriting and keyboarding are important, teacher attitudes towards the subject matter are reflected in their teaching practices (Baylor and Ritchie 2002; Graham et al. 2008). Graham et al. (2008) surveyed teachers about teaching handwriting. Of the 174 teachers who completed the survey, only 12 % felt adequately prepared to teach handwriting. Although their students were given handwriting grades, only 6 % of teachers used norm-based criteria. Thirty-six percent of the teachers felt their students' handwriting was adequate. Twenty-three percent of the students were felt to have handwriting issues. Although the teachers appeared to have good intentions in teaching handwriting, this study questions the quality of their preparation for and effectiveness in handwriting instruction (Graham et al. 2008).

Technology in the classroom is fairly new; veteran teachers can lack the competence needed to bring a broad range of opportunities to the students (Baylor and Ritchie 2002). In order for teachers to expand opportunities into the classroom, they need to first see relevant use and then have extended experience with new ideas and skills (Baylor and Ritchie 2002). Students have software available to practice basic skills (Baylor and Ritchie 2002), but do students use it effectively? (Freeman et al. 2005). In 1997 the President's Committee of Advisors on Science and Technology

found teachers received very little support in gaining technology competency (Baylor and Ritchie 2002). Feeling comfortable with computer basics could increase teachers' competence and thus improve student performance (Chwirka et al. 2002).

In the United States, England, and Ireland the guidelines for keyboarding and handwriting tend to be non-specific. In the United States the Federal Government recommends schools establish programs reflecting research and effective practice to teach writing (United States of America, US Department of Education 2004), but these are subject to voluntary state standards, with most curriculum decisions made at the local school district level. Pennsylvania handwriting guidelines have kindergarten students (5–6 years) beginning to form letters correctly, with 1st graders (6–7 years) using capital letters correctly (United States of America, PA Department of Education 2011); keyboarding guidelines have 4th grade (9–10 years) students able to demonstrate keyboard use, 7th grade (12–13 years) students demonstrating age appropriate skills and 10th grade (15–16 years) students able to use touch-keyboarding with expected speed and accuracy (United States of America, PA Department of Education 2002). The state of Texas has statewide educational standards including grade curricular requirements for handwriting (United States of America, TX Department of Education 2010), but emphasis is on form rather than fluency. For keyboarding, requirements are more general, with 3rd through 5th (8–11 years) to use touch keyboarding with good ergonomic positioning (United States of America, TX Department of Education 2011).

England, recognizing that literacy has emphasized reading, with increased scores in this area, while writing had not, developed The National Literacy Strategy—Developing Early Writers (England, Department of Education and Employment 2011). This document recognizes handwriting instruction as an important foundation to improving composition skills, with gross and fine motor skills developed in early years contributing. Ergonomics and a multisensory approach are encouraged, with supervised practice; but the particulars appear to be left to individual schools. Again, form is addressed rather than fluency. Keyboarding instruction was not included in this document.

Ireland's Council for Curriculum and Assessment defines handwriting in relation to legibility, fluency and speed in their Literacy in Early Childhood and Primary Education (3–8 years) (Kennedy et al. 2012). It is recommended that handwriting be taught in letter groups, rather than the alphabet, using multisensory approach, which includes vision, hearing, kinesthesics and touch. Fluency is defined as being automatic, smooth writing without noticeable breaks taken within or between words. Desk set up is specified for right and left handed students, including posture, chair height and pencil grasp. Composition writing is discussed in stages that include stages 1 and 2 of motor learning. Teachers are to be responsible for assisting students in developing skills for digital literacy including keyboarding, noting that technology is constantly changing. Research suggests digital technology could support writing development, but no specifics were mentioned. The teacher training and continuing education for best practices (Ireland, Department of Education and Skills 2011).

The Need for OT Consultative Services

As school-based OT consultative services have increased, teachers have recognized OT's contribution to enhancing a student's skill level (Barnes and Turner 2001; Reid et al. 2006) in written communication. However, this consultative service is limited to working with individual teachers and can be limited by lack of time for collaboration within a classroom schedule or the inability of the OT to attend team meetings (Barnes and Turner 2001; Reid et al. 2006). The OT consultative model could be expanded to formal programs for both pre-service and practicing teachers (Wehrmann et al. 2005), facilitating knowledge sharing on a broader realm than individual classrooms. When discussing whether or not students need proficient handwriting, when they will ultimately rely on keyboarding for written communication, OT provides a unique, significant perspective. At the university and continuing education level, the consultative OT can introduce the concepts of motor learning, with age appropriate expectations for students to facilitate success. This model could reach a broader audience of teachers who will bring the knowledge into classroom and change practice (Reid et al. 2006). Teachers can gain valuable information assisting them with instructional strategies to help students develop handwriting fluency (Asher 2006), while increasing their comfort level for instruction (Baylor and Ritchie 2002).

Handwriting and keyboarding are not mutually exclusive; rather keyboarding builds on the skills of handwriting. There is a fair to moderate correlation between handwriting legibility and keyboarding speed, and keyboarding speed/skill acquisition with handwriting speed (Freeman et al. 2005). This suggests the student with handwriting difficulties might be more competent in keyboarding, after structured instruction (Rogers and Case-Smith 2002). Each skill uses different motor skills, but both involve motor learning. By 2nd grade, most students have handwriting fluency. Research states it is more effective to teach keyboarding to students in 5th grade or later (Table 1). Therefore, handwriting instruction is important in early grades, followed by keyboarding instruction in later

elementary grades. Each skill has its place and time when fluency contributes to the quality of composition skills. Working as a team, OT and teachers can facilitate the goal of proficient written communication.

Although the governments of England, Ireland and the United States each recognize the importance of teaching handwriting, guidelines are often left to individual districts or schools. Both the United States and England seem oriented toward form rather than fluency; Ireland, although recognizing the importance of handwriting fluency provides little guidance for how to achieve this. Keyboarding instruction is not mentioned in England's National Literacy Strategy—Developing Early Writing (2001). Ireland sees digital technology as potentially supportive to writing composition; the United States has different expectations for developing touch-keyboarding skills, depending on state, district, and school. Research suggests teachers' attitudes and comfort level impact their teaching practices. Using the OT consultative model at the continuing education and university level could facilitate an understanding of motor learning, while supporting age appropriate expectations. Enhancing teachers' knowledge of comfort level with teaching both handwriting and keyboarding supports success of all students as they strive to attain fluency in written communication.

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