Application of Motor Learning Principles to Handwriting Instruction and Intervention

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Introduction

Approximately 12-25% of school-age children experience difficulty with handwriting (Barnett, 2006; Graham & Weintraub, 2006; Graham et al., 2008). Despite the growing use of computers and technology in the classroom, handwriting remains an essential life skill (Feder & Majnemer, 2007; Cahill, 2009) and thus, a large portion of school-age children are faced with the consequences of poor handwriting. The implications of handwriting difficulties are numerous and have been well documented. For example, difficulty with handwriting requires greater attentional resources to be directed to letter formation, which can interfere with a child's confidence and competence as a compositional writer (Baker, Gersten, & Graham, 2003; Case-Smith, 2002; Donica, 2010; Graham, Harris, & Fink, 2000; Graham & Weintraub, 1996; Medwell & Wray, 2008). Poor legibility can interfere with teachers' perceptions and grading of students' written work (Briggs, 1970; Connelly, Campbell, McLean, & Barnes, 2006; Markham, 1976), and slow handwriting speed can contribute to incomplete assignments or increased time to finish written work (Berninger, Mizokawa, & Bragg, 1991). Academic failure as well as lowered self-esteem can result from problems associated with poor handwriting (Rubin & Henderson, 1982; Tseng & Cermak, 1993; Feder & Majnemer, 2007).

In England, the Department of Education and Employment (2001 as cited in Donica, 2010) and Taylor (2001) recommend the use of sensory-motor strategies for handwriting instruction. Sensory-motor approaches to intervention for children referred for handwriting difficulties are also favoured among school-based occupational therapists in North America (Feder, Majnemer, & Synnes, 2000; Woodward & Swinth, 2002). However, accumulating evidence suggests that sensory-motor strategies are not effective in improving, and in some cases worsen, handwriting legibility in struggling writers (Sudsawad, Trombly, Henderson, & Tickle-Degnen, 2002; Denton, Cope, & Moser, 2006; Weintraub, Yinon, Bar-Effrat Hirsch, & Parush, 2009; Zwicker & Hadwin, 2009). Given that "automatic legible handwriting is an essential basis for written expression" (Sheffield, 1996, p. 22) and automaticity is the single best predictor of length and quality of written composition (Graham, Berninger, Abbott, Abbott, & Whitaker, 1997), the focus of handwriting instruction and intervention should be on achieving this goal. With this aim in mind, motor learning theory may have an important role to play in informing our approach to handwriting skill development (Zwicker & Harris, 2009).

While handwriting is more than a motor act (Medwell & Wray, 2007), we contend that the application of motor learning theory to handwriting instruction and intervention can help to achieve automaticity in the mechanics of writing, thereby freeing up cognitive resources for the content and composition

of writing. Thus, the purpose of this paper is to review key motor learning principles that may be applicable to handwriting instruction and intervention. We then demonstrate the application of these motor learning principles in a handwriting program we developed called *Printing Like a Pro!* (see http://www.childdevelopment.ca/School-Age_Therapy_Practice_Resources.aspx). While we have not empirically validated this program, it is grounded in motor learning theory and is based on current evidence for handwriting intervention.

Principles of Motor Learning

Motor learning is defined as "a set of processes associated with practice or experience leading to relatively permanent changes in the capability for movement" (Schmidt & Lee, 2005, p. 302). In the case of handwriting, this "permanent change" would translate into automaticity of the skill, such that little conscious effort is required for legible letter formation. As it is beyond the scope of this paper to thoroughly review motor learning theory (see Schmidt & Lee, 2005; Zwicker & Harris, 2009), we will highlight key motor learning principles that can be applied to handwriting skill development: stages of motor learning, practice, and feedback.

Stages of Motor Learning

Fitts and Posner (1967) describe three stages of motor learning: cognitive, associative, and autonomous. During the *cognitive stage*, an individual may have a general idea of the movement required for a task but might not be sure how to execute that movement. Cognitive strategies are needed to guide motor behaviour, such as concerted attention to task requirements and/or verbalization of movement strategies. This stage is also referred to as the verbal motor stage (Adams, 1971). Performance during this stage is likely to be highly variable with a large number of errors. The second, intermediate stage, of motor learning is the *associative stage*. Skills become more refined with practice, resulting in greater consistency of performance and fewer errors. Less guidance is required during this stage to allow the individual to make errors so that he or she can learn to adjust subsequent movements independently (Poole, 1991). The ability to learn from errors is thought to promote generalization to similar motor tasks. Automaticity of motor learning occurs in the third stage, the *autonomous stage*. At this stage, the motor skill has been learned and little cognitive effort is required to execute it. Automaticity is evident when a motor skill can be performed while engaging in another task, such as a student handwriting while simultaneously processing auditory information and cognitively composing (e.g., quickly writing legible notes during a lecture). Evidence from neuroscience indicates that less brain activation is required when automaticity of movement has been achieved (Poldrack et al., 2005; Wu, Kansaku, & Hallett, 2004), suggesting that fewer attentional demands are required.

Practice

Practice is one of the most important factors in improving handwriting (Hoy, Egan & Feder, 2011) and is a key tenet of motor learning theory (Zwicker & Harris, 2009). Having an adequate amount (dose) of practice is critical to producing meaningful gains in handwriting performance. In a recent systematic review of handwriting intervention studies, Hoy et al. (2011) recommend a minimum of 20 sessions, twice per week, to produce improvements in handwriting.

In addition to the *frequency* and *duration* of practice, *practice schedules* are another important factor to consider. For example, *distributed practice* involves practising a task alternating with periods of rest and is considered superior for motor learning compared to massed practice, where one continually practices a task with little or no rest (Donovan & Radosevich, 1999). *Blocked practice* involves repetitive practice of the same task and generally results in improved *motor performance*; however, *random practice* tends to produce superior results in *motor learning* (Lee, Swanson, & Hall, 1991). Blocked practice is thought to be most beneficial when first learning a skill (i.e., cognitive stage), with random practice more effective at later stages (i.e., associative and autonomous stages) (Baker, 1999).

Feedback

Feedback is another essential component to promote motor learning. Feedback may be *intrinsic* or *extrinsic* (Poole, 1991; Baker, 1999; Zwicker & Harris, 2009). *Intrinsic* feedback primarily stems from the sensory system and provides information before, during, and after the movement. For example, struggling writers may grip the pencil tightly and press firmly when writing; as a result, they receive intrinsic feedback which is interpreted as a sore hand when writing. *Extrinsic* feedback comes from external sources, such as information from a teacher or therapist to improve motor skill acquisition.

The *timing of feedback* can also influence motor learning. Feedback can be given during the movement (concurrent), right after the movement (immediate), at the completion of movement (terminal), or after a delay (Schmidt & Lee, 2005). Feedback can also be given consistently (i.e., after every trial) or sporadically (i.e., after some but not all trials). Contrary to what one might expect, sporadic feedback after a delay is superior for motor learning to consistent feedback given immediately after the movement (Winstein & Schmidt, 1990). The delay in feedback given over some trials allows the individual to determine what factors are influencing performance and prevents reliance on external feedback to learn the skill. However, children may benefit from feedback 100% of the time when first learning a skill (Sullivan, Kantak, & Burtner, 2008).

The final motor learning terminology we will discuss is k*nowledge of results* and *knowledge of performance* (Zwicker & Harris, 2009). Knowledge of results is terminal feedback given verbally about the outcome of movement in terms of the goal. In contrast, knowledge of performance is feedback on the specific components of the movement pattern, not on the achievement of the goal.

Application of Motor Learning Principles: Printing Like a Pro!

Consistent with the latest evidence of handwriting interventions (Denton et al., 2006; Weintraub et al., 2009; Zwicker & Hadwin, 2009), we opted to develop a printing program based on motor learning principles. *Printing Like a Pro!* is a cognitive-based, task-specific printing practice program designed for the primary years (Year 2 and 3; ages 6-8 years). The program was primarily developed for students with mild motor impairments, such as Developmental Coordination Disorder, Learning Disabilities, and Autism Spectrum Disorder (Montgomery & Zwicker, 2011). The goal of the *Printing Like a Pro!* printing program is for young students

to learn how to write letters automatically, accurately, and fluently using efficient motor patterns (Montgomery & Zwicker, 2011). The program is comprised of worksheets of letters (one letter per page) and organized in a developmental progression of "letter groupings." Letters are grouped based on common formational characteristics; grouping letters with similar stroke patterns is thought to reinforce correct motor patterns for letter formation (Benbow, 1990) and reduce problems of reversals, rotations, and inversions (Alston & Taylor, 1987). Lower case letters are introduced before upper case (Jones & Christensen, 1999; Graham et al., 2000; Berninger, Abbott, Augsburger, & Garcia, 2009; Graham 2009; Montgomery & Zwicker, 2011; Zwicker & Hadwin, 2009), as lowercase letters are more frequent than capital letters in the text that students read and write (Berninger et al., 2009).

Cognitive Stage

While the three sequential stages of motor learning (Fitts & Posner, 1967) informed the development of *Printing Like a Pro!*, our emphasis was on the cognitive stage of motor learning. At this stage, the student tries to understand the requirements of the motor task but only has a vague idea and is unsure of how to do the task (Poole, 1991). For example, a young student with handwriting challenges may initially use an inefficient or awkward sequence of strokes to "draw" an approximation of a letter. In this first stage, the student requires direct instruction on how to print individual letters. Although some typically developing children appear to learn handwriting intuitively, most children must be taught handwriting using direct instruction to achieve writing fluency (Case Smith, Holland, & Bishop, 2011; Donica, 2010; Graham, 2009; Sheffield, 1996). However, according to Donica (2010), over the past 30 years, the focus has moved away from direct handwriting instruction to a whole-language approach, with teachers providing individual reactive teachable moments instead of direct instruction. This approach to learning handwriting requires students to function at a cognitively higher level of learning, which may exceed their handwriting abilities (Asher, 2006). When fundamental handwriting skills are not explicitly taught, students who struggle with these skills are not identified until the demands for written production increase (Case Smith et al., 2011). At this point, it is often felt to be too late as the students are past the primary years when teaching of proper handwriting is typically done. In summary, available research consistently supports that students, especially those who struggle with handwriting, benefit from carefully planned, explicit, and direct handwriting instruction. (Case Smith et al., 2011; Donica, 2010; Graham, 2009; Hoy et al., 2011; Sheffield, 1996).

In *Printing Like a Pro!*, we use several explicit handwriting strategies: modeling with visual cues, self-talk, self-evaluation, and practice (Montgomery & Zwicker, 2011). The first feature - direct instructional *modeling with numbered arrows cues* – is utilized to provide a motoric model for the student to imitate with numbered arrows showing order and direction of stroke for each letter (Berninger et al., 1997; Graham et al., 2000; Graham 2009; Montgomery & Zwicker, 2011; Zwicker & Hadwin, 2009). In this initial stage of learning, it is extremely important that the learner understands the goal (Poole, 1991). Instructions to the child should focus on the important perceptual cues and essential aspects of the letter, combined

with demonstration of proper letter formation to give the student an idea of the desired movement (Poole, 1991). The numbered arrows on each letter clarify understanding and highlight the relevant features of each letter. Specifically, while modeling letter formation on a chalk board or whiteboard, the teacher or therapist describes out loud the direction of movements with use of the numbered arrows (Graham & Weintraub, 1996; Graham et al., 2000; Montgomery & Zwicker, 2011; Zwicker & Hadwin, 2009). The student imitates the demonstration, followed by more copying practice (Graham, 2009; Montgomery & Zwicker, 2011; Zwicker & Hadwin, 2009).

As previously stated, Adams (1971) refers to the *cognitive stage* as the verbal motor stage of motor learning. At this stage, the student should be encouraged to utilize the second feature - *self-talk* – which is a learning strategy to focus on metacognitive awareness via verbal mediation to guide letter formation (Zwicker & Hadwin, 2009). The letter worksheets have a "speech bubble" as a reminder for self-talk instructions for each letter. The student is encouraged to verbalize proper letter formation while printing, which guides the child to perform the desired sequence of movements. (Graham & Weintraub, 1996; Graham et al., 2000; Weintraub et al., 2009; Zwicker & Hadwin, 2009). Using a verbal mnemonic to sequence the correct order of strokes in letter formation aids the student to both form letters with better legibility and become more efficient (speed).

Improved handwriting performance is contingent upon the student's conscious effort to attend to the salient features of each letter. This is achieved in the program through the third feature - *self-evaluation* (Montgomery & Zwicker, 2011). The student is encouraged to look and see how closely their letter formation matches the target letter (Graham & Weintraub, 1996; Jones & Christensen, 1999; Graham et al., 2000; Montgomery & Zwicker, 2011; Weintraub et al., 2009; Zwicker & Hadwin, 2009). The student then circles their best-formed letters based on set criteria (Graham 2009; Montgomery & Zwicker, 2011; Zwicker & Hadwin, 2009). By allowing the student to self-evaluate, the teacher or therapist can assess the accuracy of the child's knowledge of results and provide supplemental information to extend learning. Therefore, through guided self-evaluation, the student becomes more aware of components of legibility; the student is then encouraged to use this information in subsequent practice attempts. Providing specific *feedback* on what the child needs to do the next time is key to enhancing motor learning; thus, the child should NOT be given the letter worksheets to complete on their own. "Practice makes perfect" is only true when the critical elements of self-evaluation, feedback, and corrective action are in place.

Practice is one of the most significant tenets of motor learning (Zwicker & Harris, 2009) and is the key to improved handwriting (Hoy et al., 2011). Consistent with motor learning theory (Zwicker & Harris, 2009) and recent evidence (Sudsawad et al., 2002; Denton et al., 2006; Weintraub et al., 2009; Hoy et al., 2011), practicing the skill of handwriting itself, and not the underlying sensory-motor components, is an essential element to improve handwriting (Zwicker, 2011). Therefore, the fourth feature of the program – *learning through repeated handwriting practice* – is essential for development and retention of motor learning of handwriting. In

the cognitive stage of motor learning, *blocked practice* of the same letter is indicated to increase performance, as the student needs to practice the *same* movement many times; through trial and error and numerous attempts to complete the task, the student begins to develop successful movement patterns (Poole, 1991). Appropriate frequency and intensity of practice is key. Shorter, more frequent lessons are suggested (Denton et al., 2006; Graham, 2009); several times a week, or even daily, with 75 – 100 minutes a week devoted to handwriting instruction (Graham, 2009). This *distributed practice schedule* (practicing a task alternating with periods of rest) is felt to be superior to massed practice (little or no rest) in contributing to motor learning (Zwicker & Harris, 2009). In a systematic review of handwriting studies, Hoy et al. (2011) suggest that handwriting practice at least twice a week for 20 sessions is necessary to produce positive outcomes. This evidence reflects the recent neuroscience literature indicating that specificity (handwriting practice) and intensity are key elements to induce neuroplastic change (Kleim & Jones, 2008). This neuroplastic change is required to produce the "relatively permanent change" associated with motor learning (Schmidt & Lee, 2005).

Associative Stage

In the *associative stage*, learners begin to refine their skills and through continuous practice and repetition, the learner's movements become more consistent, and errors begin to decrease (Poole, 1991). To facilitate handwriting development in the *associative stage* learning, a second set of classroom friendly worksheets was developed (*letter group review* - non random and random order - as well as *word* practice). Practice using the *associative stage worksheets* occurs once a student is able to form individual letters using correct letter formation. This second set is aimed at providing additional practice within letter groupings (individual letter review worksheets) to further focus on consistency in letter formation as well all components of legibility. The student should also be encouraged to focus on good legibility (form, closure, quality, alignment, height and size of letters as well as spacing).

As discussed above, blocked practice is felt to be most beneficial in the early stages of learning, whereas *random* practice is felt to be most effective for students in the later stages (*associative stage*) of refining an already learned skill (Baker, 1999). Use of random and variable practice conditions yields better retention (Baker, 1999) and can facilitate generalization and transfer of motor skills to the naturalistic (classroom) environment (Poole, 1991; Baker, 1999). Therefore, random order of practice of individual letters was incorporated into the letter review worksheets. This encourages the student to recall letter formation patterns out of the typical sequence practiced and strengthens the motor pattern associated with each specific letter.

Additionally, after each letter group review practice, students can begin to combine all skills learned in practice of handwriting words (as per letter groupings), for best carryover (Graham et al., 2000; Graham, 2009). Handwriting word practice reinforces letter formation and generalization to the printed word (Graham et al., 2000; Graham, 2009; Montgomery & Zwicker, 2011). The majority of words utilized in the worksheets are from the Sitton's High-Frequency Writing

Words list[1], the Dolch word list[2] and/or the most common words in the English language list[3]. The words were selected with extensive consultation with experienced educators. High frequency words were chosen to reinforce early reading skills. Initial words are short, simple, and very easy to read and write. The words were grouped in "word families" whenever possible. Over the course of the worksheets, the words become slightly more challenging to read and write.

During the *associative stage, less guidance* is provided and the student is allowed to make errors so that he or she can learn to adjust subsequent movements independently (Poole, 1991). Therefore, on the second set of worksheets guidance and explicit visual cues are gradually faded (i.e., numbered arrows, dotted interline). Additionally, reliance on self-talk (speech bubble) is faded to self-thought (thought bubble) and to no instructional cuing for letter formation.

Feedback should be more precise, but it should start to decrease so that the learner becomes less dependent on it in the *associative stage* (Poole, 1991). To decrease reliance on feedback from the therapist or teacher, students are encouraged to develop their own *error-detection* mechanisms (Winstein, 1987 as cited in Poole, 1991). Learning from errors is thought to promote generalization to similar motor tasks (Zwicker & Harris, 2009). Therefore, in the second set of worksheets, the student is requested to not only circle their best formed letters (*self-evaluation*) but also requested to "redo" a poorly written letter or word to match the target letter, therefore utilizing both *error-detection and self-correction*.

Autonomous stage

Automatic, legible handwriting allows fluent writing and enables more advanced composition (Berninger et al, 1997). Automaticity in handwriting is of key importance in composing (Medwell & Wray, 2007). Handwriting needs to be at an autonomous level so that a student is free to concentrate on spelling, and to focus on higher-level thought and written expression and content (Sheffield, 1996).

In the final stage, the *autonomous stage*, the skill becomes automatic. The skill requires little, if any, cognitive processing, so it is less susceptible to interference from other ongoing activities or distractions in the environment (Poole, 1991). Once letter formation and legibility components have become automatic, the student can print while either processing auditory directions or while cognitively composing. Instructions and learning in this phase focus on a particular aspect of the skill (Poole, 1991). Therefore, as long as some parts of the skill are automatic, the student can focus on other aspects of performance (Poole, 1991). The student will be able to print while composing his thoughts and functional practice should

1 Available from:
http://www.dallassd.com/resources/Parent%20Resources/Sitton%20Spelling/High%20Frequency%20Writing%20Words.htm
[Retrieved June 23, 2012]

2 Available from:
http://en.wikipedia.org/wiki/Dolch_word_list
[Retrieved June 23, 2012]

3 Available from:
http://en.wikipedia.org/wiki/Most_common_words_in_English
[Retrieved June 23, 2012]

be focused on increasing speed without sacrificing accuracy. At this stage learning is transferred through writing practice in the classroom. Additionally, *Printing Like a Pro!* "skill boosting" worksheets will be developed to focus on classroom friendly activities to further increase legibility and especially to increase speed.

The Printing Like a Pro! Program

The *Printing Like a Pro!* program, including worksheets, is available for free download and instructional use from the SunnyHill Health Centre for Children Child Development and Rehabilitation website - School-Age Therapy Practice Resources: http://www.childdevelopment.ca/School-Age_Therapy_Practice_Resources.aspx. School and home versions are available to specifically target use by teachers or families. We have also created "Legibility Checklists" for occupational therapists to use to guide intervention in a consultative model. We encourage you to access this printing program and use it in your practice or your classroom. Queries or feedback about the program can be directed to Ivonne Montgomery at imontgomery@cw.bc.ca. Please regularly check back on the website as we are continuing to refine the program and develop additional materials.

As we mentioned, *Printing Like a Pro!* has not been empirically validated. However, the program is based on current evidence and incorporates key principles from motor learning theory. While handwriting is much more than a motor skill, helping children to learn the mechanics of handwriting provides a solid foundation on which to build higher order writing and composition skills. We hope that you find *Printing Like a Pro!* a useful resource to accomplish this goal.

References

Adams, J. A. (1971). *A closed-loop theory of motor learning. Journal of Motor Behavior*, 3, 111-149.

Alston, J., & Taylor, J. (1987). *Handwriting: Theory, research, and practice.* New York: Nichols Publishing.

Asher, A. (2006). *Handwriting instruction in elementary schools. American Journal of Occupational Therapy*, 60, 461–471.

Baker, B. (1999). Principles of motor learning for school based occupational therapy practitioners. *School System Special Interest Section Quarterly*, 6(2), 1-4.

Baker, S., Gersten, R., & Graham, S. (2003). Teaching expressive writing to children with learning disabilities: Research-based applications and examples. *Journal of Learning Disabilities*, 36, 109-123.

Barnett, A. (2006). *Handwriting: Its assessment and role in the diagnosis of Developmental Coordination Disorder.* Leeds Consensus Statement. Retrieved June 23, 2012 from http://www.dcd-uk.org/seminar2.html

Benbow, M. (1990). *Loops and other groups: A kinesthetic writing system.* Tucson, AZ: Therapy Skill Builders.

Berninger, V.W., Abbott, R.D., Augsburger, A., & Garcia, N. (2009). Comparison of pen and keyboard transcription modes in children with and without learning disabilities. *Learning Disabilities Quarterly*, 32, 123-141.

Berninger, V.W.Mizokawa, D.T. & Bragg, R. (1991). Theory-based diagnosis and

remediation of writing disabilities. *Journal of Educational Psychology*, 29, 57-79.

Berninger, V.W., Vaughan, K.B., Abbott, R.D., Abbott, S.P., Woodruff Rogan, L., Brooks, A., Reed, E., & Graham, S. (1997). Treatment of handwriting problems in beginning writers: Transfer from handwriting to composition. *Journal of Educational Psychology*, 89, 652-666.

Briggs, D. (1970). Influence of handwriting on assessment. *Educational Research*, 13, 50-55.

Cahill, S.M. (2009). Where does handwriting fit in? *Intervention in School and Clinic*, 44, 223-228.

Case-Smith, J. (2002). Effectiveness of school-based occupational therapy intervention on handwriting. *American Journal of Occupational Therapy*, 56, 17-25.

Case Smith, J., Holland, T., & Bishop, B. (2011). Effectiveness of an integrated handwriting program for first-grade students: A pilot study. *American Journal of Occupation Therapy*, 65, 670-678.

Connelly, V., Campbell, S., McLean, M. & Barnes, J. (2006). Contribution of lower order skills to the written composition of college students with and without dyslexia. *Developmental Neuropsychology*, 29, 175-196.

Denton, P., Cope, S., & Moser, C. (2006). The effects of sensorimotor-based intervention versus therapeutic practice on improving handwriting performance in 6-11 year-old children. *American Journal of Occupational Therapy*, 60, 16-27.

Donica, D. (2010). A historical journey through the development of handwriting instruction (Part 2): The occupational therapists' role. *Journal of Occupational Therapy, Schools and Early Intervention*, 3, 32-53.

Donovan, J. J., & Radosevich, D. J. (1999). A meta-analytic review of the distribution of practice effect: Now you see it, now you don't. *Journal of Applied Psychology*, 84, 795-805.

Feder, K.P., & Majnemer, A. (2007). Handwriting development, competency, and intervention. *Developmental Medicine & Child Neurology*, 49, 312-317.

Feder, K., Majnemer, A., & Synnes, A. (2000). Handwriting: Current trends in occupational therapy practice. *Canadian Journal of Occupational Therapy*, 67, 197-204.

Fitts, P. M., & Posner, M. I. (1967). *Learning and skilled performance in human performance*. Belmont, CA: Brooks/Cole.

Graham, S. (2009). Want to improve children's writing? Don't neglect their handwriting. *American Educator, Winter*, 20-27/40.

Graham, S., Berninger V.W., Abbott, R., Abbott, S., & Whitaker, D. (1997). The role of mechanics in composing of elementary school students: A new methodological approach. Journal of Educational Psychology, 89, 170-182.

Graham, S., Harris, K.R., & Fink, B. (2000). Is handwriting causally related to learning to write? Treatment of handwriting problems in beginning writers. *Journal of Educational Psychology*, 92, 620-633.