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Brain research shows why handwriting should be taught in the computer age

Karin James and **Virginia Berninger** explain how brain research has shown that teaching handwriting is not only helpful in itself but has positive effects on letter learning, word reading, and writing. The practical implications are clear: keyboarding complements but should not be a replacement for the teaching of handwriting in the digital age.

This article features findings of two research teams each headed by one of the two authors whose research on the brain bases of writing has shown the importance of handwriting. Both authors are committed to sharing with teachers brain research relevant to instruction and learning. First, research studies and findings are described for children before entry to school and formal literacy instruction. Second, studies and findings for children in the elementary and middle school grades are described. Finally, applications of the research findings for teaching students with learning difficulties are discussed. The theme throughout is why should educators still teach handwriting in the computer era and why should they be concerned about students who struggle with handwriting.

A surprising and unexpected finding in the programmatic research of the second author was that when first graders, who had been identified as low achieving in handwriting, were given specialized handwriting instruction which had been shown to be effective in another study of first graders who were low achieving in handwriting (Berninger et al., 1997), these students improved in word reading even though reading had not been taught (see Study 2 in Berninger et al., 2006). Programmatic brain research by the first author provides insights into why the students given this specialized handwriting instruction improved in word reading.

Self-Generated Actions in Preliterate Children

During early development, self-generated actions serve to enhance hand-eye co-ordination (Needham

et al., 2002), depth perception, (Bertenthal & Campos, 1984), sound recognition (Pelfrey et al., 2012), spatial understanding (Siegal & White, 1995) and language development (eg. Smith & Gasser, 2005). What if learning to perceive letters and read words is also facilitated by *producing* them? Indeed, research has shown that adults (James & Atwood, 2009; Longcamp et al., 2008) and children (Li & James, 2016; Longcamp et al., 2005) learn symbols better if they write them by hand during learning than through other forms of practice including visual,

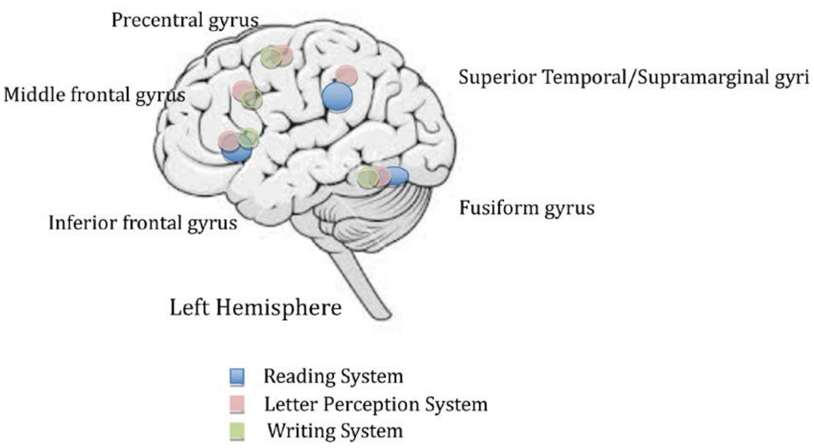

Figure 1. A schematic depiction of three brain systems underlying literacy in the adult. Of note is the overlap among systems suggesting common underlying mechanisms. See text for more detail. (From James, 2017)

auditory or typing.

Brain research provides insights into *how* handwriting facilitates perceiving letters and reading written words. This research is grounded in the hypothesis that handwriting affects symbol learning by creating a network that includes both sensory and motor brain systems. The brain system that underlies efficient letter and word processing is well known. This so-called ‘reading network’ in literate adults involves the recruitment of the left fusiform gyrus in the ventral temporal lobe, the left superior temporal gyrus/inferior parietal lobule, and the inferior frontal gyrus (e.g. Dehaene, 2009) (see Figure 1). Perceiving individual letters requires these regions plus the left middle frontal gyrus and the left dorsal precentral gyrus (eg. James & Gauthier, 2006). Importantly, *writing letters* by hand recruits almost the identical system in the literate adult, even when the participants do not see

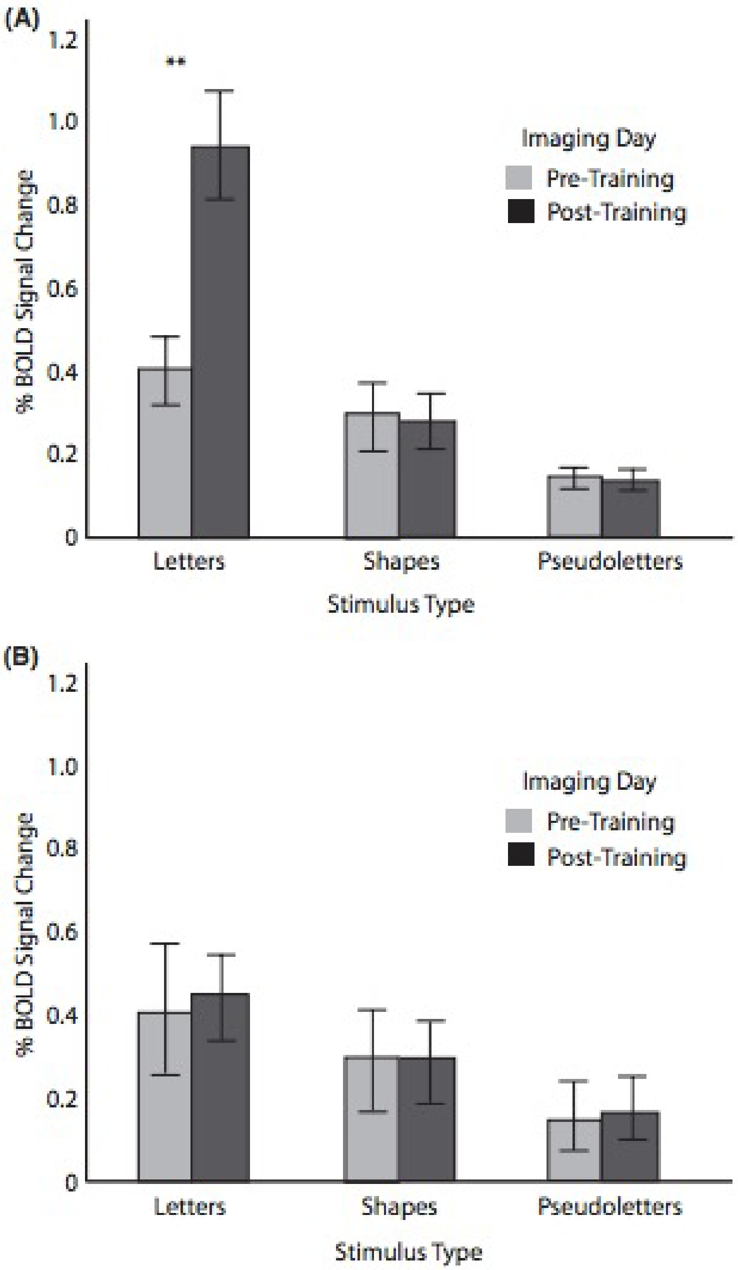

Figure 2. Left posterior fusiform region of interest from James, 2010. (a) Percentage blood oxygen-level-dependent (BOLD) signal change as a function of stimulus type during pre-training and post-training imaging sessions for the handwriting training group. (b) Percentage BOLD signal change as a function of stimulus type during pre-training and post-training imaging sessions for the visual-only training group. Error bars represent standard error of the mean; ** depict significant differences at $p < .01$; and * depict significant differences at $p<.05$.

the target letters (James & Gauthier, 2006) (see Figure 1). However, research is also needed on whether in children the self-generated actions involved with handwriting serve to *create* the connection among perceptual systems (fusiform gyrus and parietal cortex) and motor systems (the regions in the frontal cortex).

Prior to age 4, most children are not able to name all the letters of the alphabet, much less print them through handwriting. Studies were therefore conducted with four year-old children to determine a) whether experience printing letters by hand *creates* the perceptual-motor brain network that underlies letter identification and word reading, and b) what kind of manual production is important for creating these brain networks.

To answer the first question, 4-year-old children were trained to learn their letters in two ways: either through hearing and saying letter names (see and say method) or through printing those same letters (James, 2010). The first condition, the ‘see and say’ method, is the one that is most commonly used when teaching pre-school children letters, the assumption being that producing the letters by hand is too difficult at this age. The participants underwent fMRI brain scanning before and after four weeks of training with letters either through the ‘see and say’ method or through printing those same letters (without saying them). Before training, there was no letter-specific activation in the brain. That is, the brains of these children responded the same way to both letters and simple shapes (such as triangles and squares). Only after the *printing training* did the visual regions that later become specialized in the literate individual for letter recognition become active. This finding was the initial evidence supporting the idea that printing letters by hand actually formed neural specialization for letters and perhaps paved the way to creating the brain systems that were used for subsequent reading. See Figure 2.

A second study was then conducted with four- and five- year-old children that compared learning letters through the seeing and saying method, printing, typing on a keyboard or tracing (James & Engelhardt, 2012). Only after printing training did the brains of the children recruit the letter recognition/reading network that is observed in adults. This finding is important in establishing that it is not just any self-generated action that leads to the formation of the systems

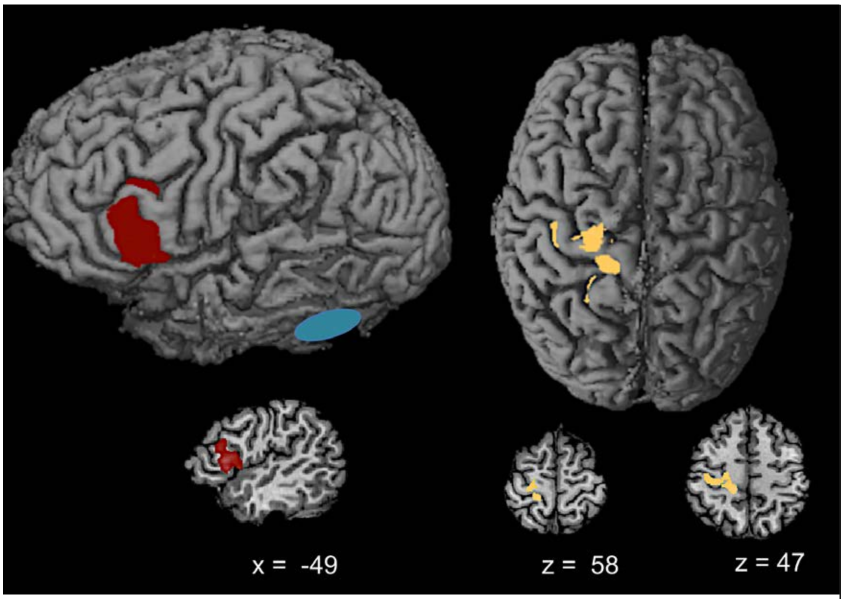

Figure 3. Effects of functional connectivity analyses from Vinci-Booher & James, 2016. (left) Functional connections between the L FuG and L IFG for the perception of letters trained through handwriting compared to shapes trained through drawing. The 'seed' region, left Fusiform gyrus is depicted in aqua. (right) Functional connections between the L FuG and dorsal sensorimotor area, including the left primary motor and somatosensory cortices, letters trained through handwriting compared to letters trained through typing. Talairach coordinates are provided. Left hemisphere is left.

that underlie reading, but that the action required is specific – in this case, simply pressing a key or even tracing a letter was not effective. Thus, two studies demonstrate that learning letters through printing creates the network of activation that is known to underlie reading in adults – even before children can read.

A third study with four-, five-, and six- year-old children was then conducted to investigate how the perceptual and motor systems become functionally connected in the brain (Vinci-Booher & James, 2016). It is possible that the network of activation that is seen during word reading and letter perception may be simply a co-activation due to producing and perceiving letters at the same time, but may not reflect a functional connection that reflects communication among many regions. Functional connectivity analyses revealed that indeed the visual regions that are active during letter perception become functionally connected to motor regions only as a result of handwriting experience (See Figure 3).

These studies showed that neither typing nor tracing a letter recruits the letter perception or reading network. If self-generated action is key, then why wouldn't typing and tracing result in the same activation as handwriting? Because of the well-known phenomena that we learn things better if we see many, variable examples than if we see a single example repeated (e.g., Gibson & Gibson, 1955), we hypothesized that copying letters results in variable examples of a given letter, whereas tracing does not. For instance, learning variable instances of a named category (such as the object 'duck') results in a more sophisticated understanding of the category. The more instances of the letter "A" that a child encounters, the better the understanding of the category of items that belong to the name "A" may be; and handwriting may be a viable route for this type of learning. When young children print letters through copying, the results are messy, and highly variable. In contrast, when they trace letters, the results are the same: a non-variable production of the letter. Variable productions that occur with handwriting may be important for learning letters.

In a fourth study this idea was tested by having 5- year-old children learn symbols of the Greek alphabet either through *seeing typed examples, copying typed examples, tracing typed examples, seeing handwritten examples* (free-hand copying of symbols), or crucially, through *tracing handwritten examples* (Li & James, 2016). This latter condition allowed them to learn variable instances (similar to printing) but through tracing instead of through free-hand copying – which equates other factors that may differ between tracing and copying. Results demonstrated that in all the conditions where children learned variable instances of the symbols (the symbols in handwritten form) their categorization ability was enhanced (See Figure 4). That is, *tracing and visually studying handwritten symbols* resulted in the same categorization accuracy as *copying handwritten symbols*. These results suggested that the reason why handwriting creates a perceptual-

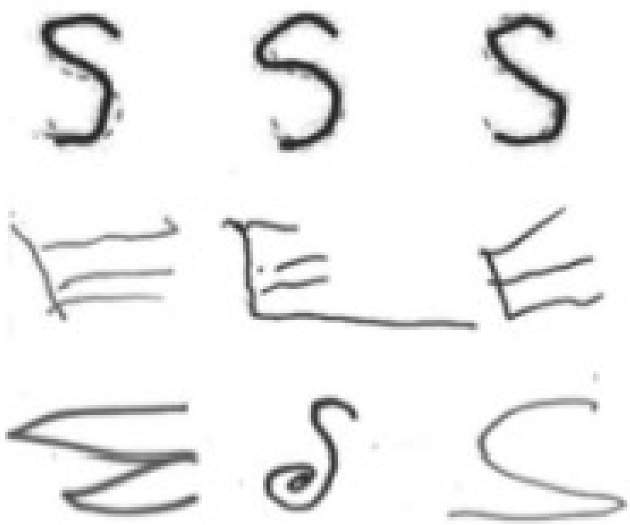

Figure 4. Examples of 4-year-olds tracing (top row) and copying (middle and bottom row) letters. Middle row is same child producing the letter three times, bottom row is three different 4-year-olds producing the same letter. (from Li & James, 2016)

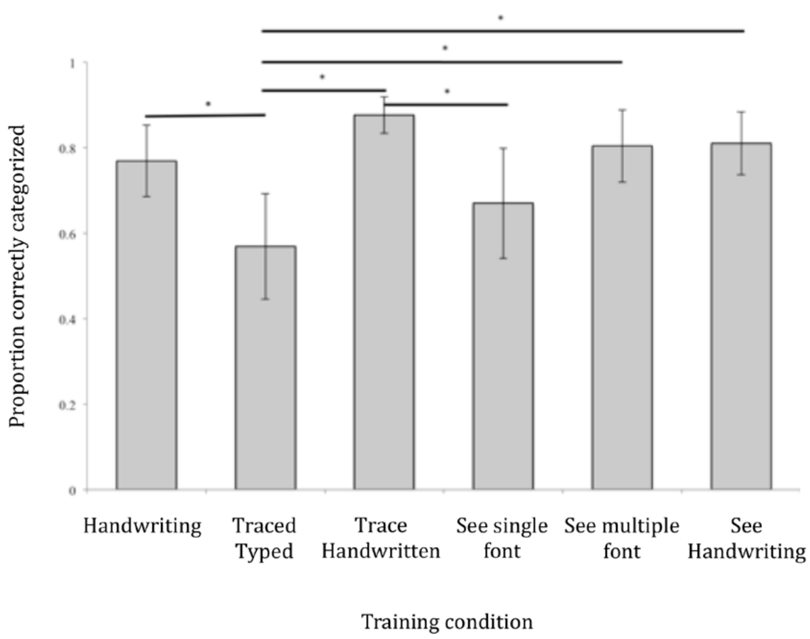

Figure 5. Differences in correct categorization of Greek symbols across training condition from Li & James, 2016. All conditions that allow learning of handwritten (variable) examples result in higher accuracy than conditions that learned repeated single examples (no variability). Note that test symbols to sort are presented in both typed and written formats, and there was no difference in sorting accuracy for the two types of test symbols. * = p<.05.

motor network and facilitates letter learning is because it allows the learner to produce and perceive variation in their learning.

A fifth study addressed whether handwriting, as a self-generated action, is really necessary for letter learning and for creating the perceptual-motor network that underlies letter perception and reading. In this study 6-year-old children learned a new script – letters written in cursive – either through self-production or through seeing an experimenter produce those same letters (Kersey & James, 2013). fMRI scans of the children's brains were then scanned using fMRI to determine whether letters written in the unfamiliar script recruited the same perceptual motor system regardless of whether they were learned through self-production or through passive viewing. The results showed that only when the letters were self-produced did seeing them at a later time recruit the perceptual- motor network. Learning the letters, even if they were variable in form, did not result in recruiting the reading network *unless the letters were self-produced*. That is, our actions in the world produce many instances of a stimulus that we then perceive.

Legible and Automatic Letter Writing during the School Years

Correlational and regression analyses showed that orthographic coding (storing and processing single letters, letter groups, and letter patterns in a whole word in working memory) and sequential finger movements were the best predictors of handwriting; and the orthographic loop for integrating letter codes and sequential production, assessed by writing the alphabet automatically from memory (legible letters in correct alphabetic order during first 15 seconds), predicts spelling and composing in the first six grades (Berninger, 2009). An instructional study showed that the most effective instruction for handwriting for first graders struggling with handwriting was combining study of numbered arrows (sequential cues) and closing eyes to see studied letter in "mind's eye" and then writing letter from memory. This method, which requires active self-generation of letters (see James, 2010; James & Engelhardt, 2012), resulted in greater improvement in handwriting and composition than (a) copying letter forms, (b) imitating a teacher modeling motor movements for forming a letter, (c) only studying numbered arrows in letters, (d) only writing viewed letter from memory, or (e) phonological awareness activities (Berninger et al., 1997). Berninger et al. (2006) compared adding orthographic coding training (treatment A) or motor training (treatment B) to combined study of numbered arrow cues for a letter, closing eyes to view letter in "mind's eye", and writing letter from memory (constant across treatments A and B); both treatments improved in word reading.

Instructional studies in the elementary and middle school grades also showed the benefits of teaching writing to all levels of language (subword letter, word spelling, and sentence/text composing) close in time to create a functional writing system (Berninger, 2009). Handwriting warm ups (writing the alphabet from memory) provided a time efficient way throughout the elementary and middle school grades to review letter formation and facilitate automatization at the beginning of writing lessons that then taught to all the other levels of language (Berninger, 2009).

Brain imaging studies also found evidence that good and poor writers in the upper elementary grades differed in orthographic coding (Richards, Berninger, & Fayol, 2009), sequential finger movements (Richards, Berninger, Stock, Altemeier, Trivedi, & Maravilla, 2009), and handwriting (Richards, Berninger, Stock, Altemeier, Trivedi, & Maravilla, 2011). Brain imaging studies of students with persisting specific learning disabilities in grades 4 to 9 validated the levels of language in the writing brain (Richards, Berninger, Yagel, Abbott, & Peterson, 2017) and the orthographic loop contributing to the self-government of the multi-leveled brain's response to writing instruction (Richards, Abbott, Yagle, Peterson, Raskind, & Berninger, 2017)

Assessment and instructional studies showed the benefits of teaching manuscript in the first two grades for transfer to reading printed texts in books and screen (Wolf, Berninger, & Abbott, 2017), cursive in the third and fourth grades for spelling and composing rate (Alstad et al., 2015), and touch typing (using both hands and not looking at the keyboard rather than hunting and pecking with one hand and looking at the keyboard) in the upper elementary and middle school grades (Thompson et al., 2016). That is, developing writers benefit from becoming hybrid writers who can produce letters using multiple modes. Computers can teach manuscript and cursive handwriting as well as using computer tools (e.g., stylus) for letter production beside keyboards (Tanimoto, Thompson, Berninger, Nagy, & Abbott, 2015).

… handwriting experience plays a crucial role in the formation of the brain network that underlies reading.

Applications to Practice

What do these studies tell us about the importance of handwriting, not only for writing but also for letter learning and reading? Handwriting and letter perception recruit the same network of activation in the literate brain, but before people are literate handwriting serves to recruit this same network, implying that handwriting experience plays a crucial role in the *formation* of the brain network that underlies reading. Thus handwriting (printing in the case of young children) is important for letter understanding and therefore for literacy development in general (writing as well as reading). Also, for children who have difficulty printing letters, learning activities for viewing and tracing variable instances of a given letter may be very helpful for acquiring letter knowledge and its applications to many aspects of literacy learning. Finally, given the research evidence for effective handwriting instruction and its importance for literacy learning (both reading and writing), the question of whether handwriting is necessary in the computer era should be replaced with the following: How can educators justify not teaching handwriting as well as computer tools during the elementary and middle school grades?

Karin Harman James is a professor of Psychological and Brain Sciences at Indiana University, and a faculty member in both the Cognitive Science and Neuroscience programs at Indiana University. Her research program centers around the interplay among sensory and motor systems in the brain and how this interplay affects learning and brain development. Dr. James' recent research has had an emphasis on how handwriting practice can have significant effects on early brain development during the pre-school years. Her research program is one of the few to use functional Magnetic Resonance Imaging (fMRI) to measure brain function in 4-6 year-old children and has been funded nationally by both the National Science Foundation and the National Institutes of Health. Dr. James is a dedicated supporter of research dissemination to broad audiences including educators, policy makers and the general public.

Virginia Wise Berninger (Ph.D. Psychology, Johns Hopkins University) retired from the University of Washington in 2016 where she had been on faculty for 30 years, taught and advised graduate students in educational psychology and served as Principal Investigator on NIH grants. From 1989 to 2008, she headed cross-sectional and longitudinal studies of typical writing and reading and related processes and reading and writing instruction for low achieving students. From 1995 to 2006 and 2011 to 2016, she headed a multidisciplinary research center that conducted research on the genetic and brain bases of specific learning disabilities and differential diagnosis and treatment of dyslexia, dysgraphia, and oral and written language disability (OWL LD). As a professor emerita, she is involved in dissemination of research findings and translation of findings to practice through professional development and consultation.

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