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Visual–motor symbol production facilitates letter recognition in young children

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Abstract Previous research has suggested that handwriting letters may be an important exerciser to facilitate early letter understanding. Experimental studies to date, however, have not investigated whether this effect is general to any visual–motor experience or specific to handwriting letters. In the present work, we addressed this issue by testing letter knowledge using three measures in preschool children before and after a school-based intervention. Participants were divided into four training groups (letter-writing, digit-writing, letter-viewing, digit-viewing) that either wrote letters or digits or viewed letters or digits, twice a week for 6 weeks. We hypothesized that the visual–motor experience of handwriting letters or digits would improve letter knowledge more than viewing experience and that this effect would not be specific to training with letters. Our results demonstrated that the writing groups improved in letter recognition—one component of letter knowledge—significantly more than the viewing groups. The letter-writing group did not improve significantly more than the digit-writing group. These results suggest that visual–motor practice with any symbol could lead to increases in letter recognition. We interpret this novel finding as suggesting that any handwriting will increase letter recognition in part because it facilitates gains in visual–motor coordination.

Keywords Handwriting · Preschool · Education · Letters · Invervention

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Introduction

Literacy instruction dominates the early elementary school day (Miller, Kelly, & Zhou, 2005; Rice, Connor, & Thomas, 2006), yet the amount of time spent teaching pre-literacy skills may not be as important as how those skills are taught. Early handwriting experience, in the form of printing letters, has a significant impact on early letter knowledge skills (Aram, 2006; Aram & Biron, 2004; Longcamp, Zerbato-Poudou, & Velay, 2005; Lonigan, Farver, Phillips, & Clancy-Menchetti, 2011; Neumann, Hood, & Ford, 2013). Among the reading readiness skills that are traditionally evaluated, the one that appears to be the strongest predictor of reading success in fourth grade is individual letter knowledge in preschool and kindergarten (Scanlon & Vellutino, 1996; Snow, Burns, & Griffin, 1998). Knowledge concerning the mechanism behind handwriting's effect on letter recognition, an important pre-literacy skill, will help educators make the best use of time allotted for literacy instruction.

Handwriting's relationship to emerging literacy skills has been widely acknowledged. Studies involving early handwriting have been included in meta-analyses and narrative summaries of early literacy research by The National Early Literacy Panel (NELP) and the National Research Council (NRC). NELP found evidence suggesting that name-writing skills yield significant correlations with later reading abilities including decoding, reading comprehension, and spelling (NELP, 2008). NRC reported key early writing skills (e.g., writing uppercase and lowercase letters independently, writing unconventionally to express meaning, and writing letters and some words when dictated) as necessary targets to prevent future reading problems (Snow et al., 1998).

Despite a growing acknowledgement of the importance of early handwriting practice, by some accounts only about 1 min of the preschool school day is spent practicing handwriting (Pelatti, Piasta, Justice, & O'Connell, 2014). The disconnect between educational practice and basic research findings may be due, in part, to the actual research itself—only a handful of studies have investigated handwriting in isolation as a potential intervention in preschool (e.g., Longcamp et al., 2005; Aram & Biron, 2004; Hall, Toland, Grisham-Brown, & Graham, 2014) and no studies have directly compared handwriting interventions to other forms of fine motor skill instruction that involve production of other forms. Though handwriting's relationship to developing literacy skills has been widely acknowledged, there are few experimental studies that specifically address the effects of preschool handwriting on emergent literacy.

There are several studies that have included handwriting as one piece of the intervention, though very few of these focus on producing individual letters by hand (i.e., letter production). In a recent review, Hall et al. (2014) found 18 studies that explicitly included handwriting as a part of a literacy intervention. Of these 18 studies, however, only 5 used letter formation by hand as an intervention (Aram, 2006; Aram & Biron, 2004; Longcamp et al., 2005; Lonigan et al., 2011; Neumann et al., 2013). In Neumann et al. (2013), children were asked to write a letter in the sky and in a personal with a pencil journal after teacher demonstration. In the

Lonigan et al. (2011) study, children were encouraged to write the letters in their names in a similar intervention schedule. In both studies, the children in the experimental group showed increased expressive knowledge, phonological awareness, and print knowledge compared to control groups. However, these interventions (a) did not investigate handwriting in isolation and (b) did not compare various intervention types. The results of these studies, therefore, may have been due to some other facet of the intervention or to the fact that the children received any intervention at all.

Studies that have included various intervention types have not examined actual handwriting (i.e., with pen and paper) in isolation. Two studies by Aram (2006) and Aram & Biron (2004) involved a twice-weekly intervention in a small group setting that involved three intervention groups: writing with stickers (instead of with a utensil), reading, writing with stickers and reading, and a control group. This research revealed that the writing with stickers group progressed more than the other groups in letter knowledge and letter retrieval measures. As they did not intervene with actual handwriting, but rather with sticker writing, it is hard to conclude that handwriting caused the changes in letter knowledge and retrieval. It may have been the sensorimotor practice involved in sticker writing. Only the sticker writing group received sensorimotor interactions with letters compared with the reading alone group, control, and to a lesser extent, the writing and reading group. Although both sticker writing and handwriting with pen and paper involve sensorimotor experience, sticker writing is qualitatively different than handwriting because writing with pen and paper involves manual dexterity with a tool that produces letterforms in a self-generated manner.

Comparing actual handwriting with other sensorimotor interventions is an important factor in demonstrating the possible efficacy of handwriting itself on emergent literacy. Only one study that we know of Longcamp et al. (2005), has compared handwriting with pen and paper to another sensorimotor intervention. In this study, one group of children learned to print letters while another group typed letters. Letter recognition was enhanced only for the printing intervention group and only for children in their 'older' group, aged 4.5 years. This is the only demonstration, to date, that compares handwriting with other types sensorimotor practice with letters. This study, however, did not include a comparison group to evaluate the role of action in letter learning—that is, a group that learned letters through visual practice alone.

Comparing handwriting to a non-active control condition is important to understand the mechanism behind handwriting's effect on letter recognition. A recent study did just this—they compared handwriting to a visual-only learning condition and, going a step further, also compared handwriting to additional measures of production (e.g., tracing). In this study, preschool children learned novel Greek symbols through either writing, tracing typed symbols, tracing handwritten symbols, visually studying typed symbols, or visually studying handwritten symbols. Results indicated that the groups that studied handwritten forms, either through tracing, viewing, or seeing their own during writing, learned the symbols better than the groups that studied typed letterforms (Li & James, 2016). These results suggest that visual experience with symbols that are highly variable in their forms (either through handwriting or through tracing handwritten forms) facilitates visual recognition To our knowledge, this is the only study to directly compare, in an experimental fashion, handwriting to visual practice in preschool children. From this study, we do not know whether the perception of variable forms results in more general gains in visual recognition or if the effect is specific to the practiced symbol.

In sum, there are surprisingly few studies to date that have experimentally investigated the effects of early handwriting instruction on emergent literacy skills. Of those studies, even fewer target handwriting experience in isolation, usually combining it with other early literacy activities. This shortcoming, along with a general lack of equated experimental groups, has led some researchers to conclude that there is an extensive gap in experimental and quasi-experimental studies on the effects of early handwriting on literacy development (Hall et al., 2014).

Present study

The present study seeks to address some of these gaps in our understanding of the relationship between handwriting and letter understanding in the preschool years. We adopt a training paradigm similar to that of Longcamp et al. (2005) but extend this work by comparing a group with handwriting training to a group that receives only visual exposure to letters, similar to Li and James (2016). We add to these two works however, by testing the specificity of handwriting training. This particular aspect of the study is important to understand whether the facilitative effects of handwriting practice are due to a general effect of learning through visually guided production of symbols, involving the fine-motor control system, or to a specific effect of handwriting letters.

Here, we address the question of whether handwriting contributes to letter knowledge because of the symbol being written (i.e., letters) or whether it is a general effect of visually guided symbol production. We, therefore, evaluated two hypotheses: First, that hand-production would facilitate subsequent letter knowledge more than visual study alone and second, that hand-production of any symbol (in this case letters and digits) would result in a facilitation of letter knowledge. Preschool-aged children underwent 6 weeks of training with either writing letters, writing digits, viewing letters, or viewing digits. Pre- and post-training tests assessed their letter knowledge through the use of three tests: one that evaluated letter naming, another to test letter categorization, and a third forced-choice letter recognition task. We hypothesized that handwriting contributes to letter knowledge because visually guided symbol production facilitates visual perceptual processes. We, therefore, expected that children trained through writing would demonstrate greater gains in letter recognition than children trained through viewing. We further expected that there would be no difference between children who trained on writing letters and those that trained on writing digits because both trainings present variable forms to the child and would, therefore, facilitate visual perceptual processes.

Methods

Participants

Eighty children were initially recruited for the study (43 females), but due to attendance issues 79 children participated (42 females). Outlier analyses (3 SD above or below the mean in any one of the pre-training tests) rendered the total sample size 76 with 42 females (Table 1). The mean age was 4.69 years ($SD = .93$) and the age ranged from 3.05 to 6.45 years. Two schools participated in this study, 36 children from one school and 40 from the other. Both were private preschools located in Bloomington, Indiana and both drew from similar, middle-to high-income households. Children were randomly assigned to one of four groups: letter-writing, digit-writing, letter-viewing, or digit-viewing. Informed consent was obtained from parents in cooperation with school administrators.

Design

The study was a pre-training-post-training mixed model design, with two between-participant factors: training experience (writing or viewing) and stimulus type (letters or digits). Age was entered into the statistical model as a covariate. Participants were randomly assigned to letter-writing ($n = 19$), letter-viewing ($n = 19$), digit-writing ($n = 19$), or digit-viewing ($n = 19$) training groups. There were three dependent measures that quantified letter knowledge based on our in-house assessments: Letter Naming, Letter Sorting (a categorization task), and Forced Choice letter recognition tasks (see below).

Materials and procedure

All participants underwent the pre-training tests (approximately 30 min total) during the first week of the study, followed by 12 training sessions over the course of 6 weeks (two per week, each one approximately 15 min), and post-training testing. All procedures occurred in the preschool setting.

Testing sessions were performed one-on-one in a small private room located in the preschool. The training sessions were performed in small groups of 4–5 children also in a small private room. There were three experimenters who were blind to the

Table 1 Demographics for each training group

Factor	Gender		Age at start of study (months)			
	n	Female	M	Min	Max	SD
Write letters	19	10	54	45	69	7.1
Write digits	19	12	52	43	68	7.2
View letters	19	9	53	42	77	12.5
View digits	19	11	53	43	76	12.2

experimental hypothesis and one that was not (DZ). All scoring was performed by the four instructors and scoring of all tests had to reach a 100% reliability level.

Letter knowledge testing

There are few standardized assessments that target visual letter knowledge in an exhaustive manner. We, therefore, designed three measures that have been used in previous studies (e.g., James, 2010; James & Engelhardt, 2012; Kersey & James, 2013; Li & James, 2016). These in-house tests were administered before and after training. We administered a letter naming task, a letter sorting task (tapping letter categorization) and a forced-choice letter recognition task, administered in that order. All scores were calculated as percent correct and, therefore, ranged from 0 to 100.

Letter naming

Children were asked to name 26 letters (A–Z) presented in a random order Zaner–Bloser typed font on 2.25 × 2.75 in. index cards.

Letter sorting (categorization)

Letter Sorting made use of a 'mailbox' into which children were asked to sort 26 index cards, each containing one letter of the alphabet (e.g., Li & James, 2016). Seventeen index cards contained age-matched handwritten letter examples and nine contained Zaner–Bloser typed letters. The mailbox had 28 slots. Twenty-six slots were labeled with letter cards in Zaner–Bloser font measuring 2.25 × 2.75 in. and two slots were left blank. Children were asked to sort letters using the mailbox system. Participants were allowed to "deliver" to empty slots if they did not know where else to go. Participants were required to place various examples of a given letter into each slot, rendering this a categorization task. No letter naming was required, and letter names were not given by the experimenter.

Forced-choice letter recognition

The forced-choice task made use of handwritten letters written by other children. Handwritten samples were used in the sorting and forced choice tasks taken from an ongoing study collecting handwriting samples from children of ages 3–5 years. Handwritten samples were compared to a typed exemplar and scored on a quality scale from 0 to 4: (0) fail; (1) poor; (2) fair; (3) good; (4) model-like by two experimenters with an agreement of 96%. Only handwritten samples that received a quality score of 4 from both experimenters were used in this study.

For the forced-choice recognition task, children were presented with age-matched handwritten letters one at a time on index cards and were asked to match the letter presented with one of four choices contained in a workbook: (1) the correct choice, which was a typed letter in Zaner–Bloser font; (2) the false choice, which was a typed pseudo-symbol created by rearranging the features of the target symbol; (3) another typed symbol similar in shape to the correct choice; and (4) a typed mirror reversal of the correct choice. For the 11 letters that cannot be reversed (e.g., M), a "matched" false choice option was presented, that was created using the same method as (2), but the result more closely resembled the correct choice, just as the reversal would bare a closer resemblance to the correct choice than a false choice (e.g., James, 2010; James & Engelhardt, 2012; Kersey & James, 2013). Examples of items from the forced-choice recognition task are shown in Fig. 1.

Training

Workbooks were constructed for writing and viewing training sessions. Each workbook, whether writing or viewing, contained half of the letters of the alphabet for letter writing or viewing workbooks or 13 digits for digit writing or viewing workbooks. Letters were selected from all letters: A through Z. Digits were selected from all single digits: 0 through 9. Some digits were repeated so that each workbook had 13 symbols to control for the amount of visual–motor practice between letter-writing and digit-writing groups. Each page of the workbook focused on a single symbol. There were two training sessions each week that consisted of learning 13 symbols. All children were trained twice a week so that they received training on a total of 26 symbols each week. All training sessions were video recorded and were periodically checked for fidelity to the training procedures.

Writing workbooks

Symbols were presented in Zaner–Bloser typed font centered within a 3.25 × 2.75 in. box located centrally in the upper third of the workbook pages. Four blank 3.25 × 2.75 in. boxes were located below the typed symbol into which children were asked to copy the symbol above (Fig. 2). The experimenter pointed to the top of each worksheet and then pointed to the boxes below saying, "Make this letter (or number) in the boxes below", and followed up if necessary to direct

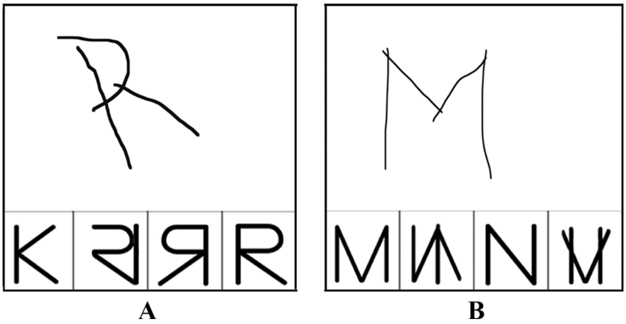
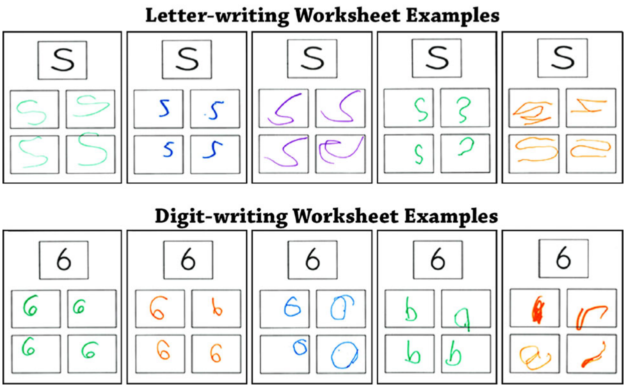


Fig. 1 Example items from the forced choice letter task. Children were presented with the handwritten exemplar and were asked to point to or circle the typed exemplar that matches it. **a** An example of a trial a letter than can be reversed. **b** An example of a trial for a letter that cannot be reversed. A "matched" false choice option is presented instead (the fourth choice, in this example)



Letter-writing Worksheet Examples

Digit-writing Worksheet Examples

Fig. 2 Examples of completed letter- and digit-writing worksheets

attention to the worksheets. The instructor did not name the letters or digits, and the children were told that naming was not necessary. Feedback was given based on effort and not accuracy. Children were allowed to use different colored markers to produce the symbols.

Viewing workbooks

Symbols were presented in Zaner–Bloser typed font at the end of a maze on the outside of a cover flap so that it could be freely viewed by the children as the experimenter solved the maze (Fig. 3a, b). An unrelated trinket of some sort (e.g., a frog for an A maze) was used as a marker of movement through the maze. The experimenter began by placing a marker at the start of the maze before proceeding through the maze (see Fig. 3). Once the marker reached the end of the maze, the cover flap was flipped over to reveal an unrelated image below the flap (e.g., a Disney character named “Oh” for an A maze) (Fig. 3c, d). The image below the flap helped to keep the children engaged in the activity and equate engagement between the writing and viewing groups as much as possible.

The viewing workbooks were designed to control for exposure time to the typed symbol in the writing workbooks. We, therefore, measured the average amount of time children spent on each symbol during writing training because this is the amount of time the typed symbol was available for viewing during writing training. We found that the youngest children generally took longer to write each symbol ($M = 62.9$ s, SE = 5.83) than the oldest children ($M = 37.0$ s, SE = 3.22). We, therefore, yoked the exposure time of the youngest children (ages 3.0–4.5 years) during the viewing conditions to the exposure time of the youngest children during the writing conditions. Exposure time of the oldest children (ages 4.6–6.5 years) during the viewing conditions were, similarly, yoked to the exposure time of the oldest children during the writing conditions. There were 37 children in the younger group and 40 children in the older group.

During writing training, children looked back and forth between the typed symbol and the symbol they were creating. To allow children the opportunity to

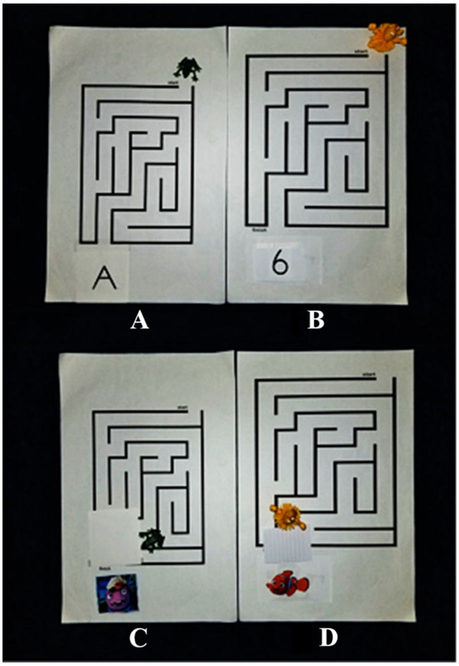


Fig. 3 Examples of unsolved **a** letter- and **b** digit-viewing mazes and of solved **c** letter- and **d** digit-viewing mazes

freely look at the symbol during the exposure time, as in the writing workbooks, the symbols were placed on top of the flap. With the symbol on top of the flap, the children were free to look at the typed symbol as the experimenter completed the maze.

Each maze in the viewing training, therefore, took approximately 30 s for the experimenter to solve for the older children and approximately 60 s for the experimenter to solve for the younger children. This ensured that children in the viewing groups had the opportunity to look at the symbol exemplar for the same amount of time as children in the writing groups.

Results

Descriptive statistics are presented in Table 2. All scores in the analysis of the three letter knowledge tasks are evaluated and reported as proportion correct.

Tests of normality of the sampling distributions were performed using the Shapiro–Wilks test and were not significant (all $p > .05$), indicating that the distributions were normal. In addition, we tested the ANCOVA assumption of homogeneity of regression slopes following the procedure outlined in Johnson (2016). For each dependent variable (naming, sorting, and recognition) we performed a univariate ANOVA on the pre-training data and the post-training data, and tested the interaction of Age with the between-subjects variables (training

Table 2 Descriptive statistics for each training group

Dependent variable	Training conditions			
	Letter writing M (SD)	Digit writing M (SD)	Letter viewing M (SD)	Digit viewing M (SD)
Letter naming				
Pre-training	72.3 (30.0)	70.0 (28.3)	72.1 (36.0)	71.5 (29.8)
Post-training	78.1 (26.9)	73.3 (29.1)	73.0 (36.1)	72.9 (26.1)
Letter categorization				
Pre-training	76.5 (27.8)	76.5 (22.8)	80.2 (25.6)	80.2 (23.3)
Post-training	85.4 (18.4)	87.1 (14.9)	82.2 (27.1)	85.4 (24.1)
Forced-choice recognition				
Pre-training	66.4 (17.4)	66.4 (18.1)	67.8 (16.3)	66.2 (17.1)
Post-training	80.0 (11.5)	74.1 (18.3)	71.3 (22.1)	70.6 (16.1)

type—writing or viewing, and training stimulus—letters or digits). Results indicated no interactions among the between-subjects variables and Age, allowing us to proceed with ANCOVA analyses, using Age as a covariate, but not including interactions with age into the ANCOVA model.

We, therefore, performed three mixed-measures ANCOVAs with testing time (pre-training, post-training) as a within-subjects factor, training type (writing or viewing) and Training Stimulus (letters or digits) as between-subjects factors. Age at the beginning of the study was entered as a covariate. Interactions with age were not included. A separate ANCOVA was performed for each dependent variable (Tables 3, 4, 5).

Although all groups improved on the letter knowledge tests with training (see Table 2 for descriptive statistics), as reflected in the significant main effects for testing time in each ANCOVA, only one significant interaction was revealed: between training type (writing vs. viewing) and testing time in the Forced Choice Letter Recognition measure ($F(1,72) = 4.1$, $MSe = 422.77$, $p < .05$). A paired sample t test performed on the pre- versus post-training data revealed a significant improvement with training for the writing group ($t(37) = 2.75$, $p < .003$) but not for the viewing group ($t(37) = .094$, $p > .05$) (see Fig. 4). There was no significant difference between the groups in the pre-training measure ($t(37) = .52$, $p > .05$.). No other interactions were significant among variables.

Discussion

Our results demonstrated that handwriting practice facilitates letter recognition as tested with a forced-choice task more than visual-only practice. They demonstrate, further, that handwriting letters and digits facilitated letter recognition to an equal extent, suggesting that sensorimotor production does not have to be letter-specific to result in gains in letter recognition.

Table 3 ANCOVA table for letter naming measure

Source	MS	F(1,72)	*n*2	*p* value
Age	7470.71	4.6	.061	.03*
Testing time	1074.32	7.51	.095	.008*
Training type	232.27	.14	.002	.70
Training stimulus	609.21	.37	.005	.55
Testing time × training type	51.58	.36	.005	.55
Testing time × training stimulus	27.71	.20	.003	.66
Training type × training stimulus	.100	.00	.000	.99
Testing time × training type × training stimulus	.90	.006	.000	.93

Age: At start of experiment, co-variate interactions with age not entered into model

Testing time: Pre-training, post-training

Training type: Writing, viewing

Training stimulus: Letters, digits

*Significant effect $p < .05$

**Significant effect $p < .01$

Table 4 ANCOVA table for letter sorting measure

Source	MS	F(1,72)	*n*2	*p* value
Age	7129.77	8.4	.10	.005*
Testing time	1776.21	10.8	.13	.002*
Training type	4.72	.005	.000	.94
Training stimulus	81.64	.08	.001	.76
Testing time × training type	411.18	2.5	.03	.11
Testing time × training stimulus	82.32	.50	.007	.48
Training type × training stimulus	2.2	.00	.000	.96
Testing time × training type × training stimulus	2.3	.01	.00	.90

Age: At start of experiment, co-variate interactions with age not entered into model

Testing time: Pre-training, post-training

Training type: Writing, viewing

Training stimulus: Letters, digits

*Significant effect $p < .05$

**Significant effect $p < .01$

Handwriting practice facilitates letter recognition

The current study replicated, in part, the work performed by Longcamp et al. (2005) by isolating handwriting practice as a training condition and comparing that experience to a non-writing control group (for review of the extant literature, see Hall et al., 2014). Taken together with other work demonstrating positive effects of

Table 5 ANCOVA table for forced-choice letter recognition measure

Source	MS	F(1,72)	*n*2	*p* value
Age	3453.60	7.5	.09	.008*
Testing time	2018.45	19.8	.21	.000**
Training type	284.90	.56	.008	.45
Training stimulus	156.63	.31	.003	.45
Testing time × training type	422.77	4.1	.054	.04*
Testing time × training stimulus	55.80	.54	.008	.46
Training type × training stimulus	31.77	.06	.001	.80
Testing time × training type × training stimulus	112.72	1.1	.015	.29

Age: At start of experiment, co-variate interactions with age not entered into model

Testing time: Pre-training, post-training

Training type: Writing, viewing

Training stimulus: Letters, digits

*Significant effect $p < .05$

**Significant effect $p < .01$

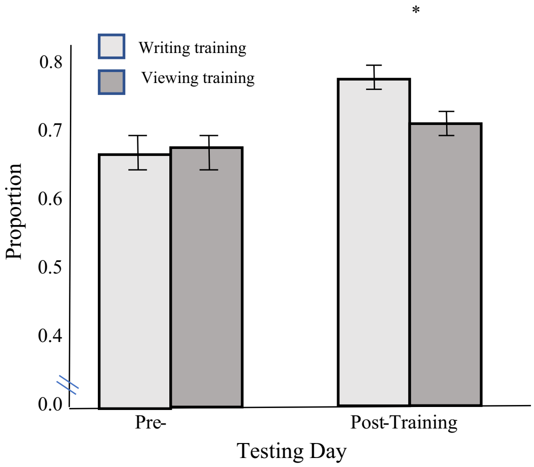


Fig. 4 The interaction between testing time (pre-training vs. post-training) and training type (writing vs. viewing) on the forced-choice letter recognition measure. Error bars are standard error of the mean

handwriting on pre- and early-literacy skills (e.g., Berninger, Abbott, Abbott, Graham, & Richards, 2002), we conclude that handwriting practice is an essential skill for early literacy development whose impact is often overlooked.

The present work extends that of Longcamp et al. (2005) in several important ways. First, we compared another form of symbol production to letter production; second, we extended the age range of children tested; third, we assessed letter knowledge in three different ways; and fourth, we equated our control group with our experimental group in terms of visual exposure times to symbols as well as maintaining attention throughout the training conditions.

In sum, this work adds to the extant literature on the effects of handwriting on early literacy skills by providing a controlled intervention study within the school setting that demonstrates the beneficial effects of writing by hand on letter recognition.

Handwriting practice with any symbol increases letter recognition

Perhaps the most novel result from the present study is that both types of handwriting training facilitated letter recognition to an equal extent. That is, regardless of whether children produced letters or digits, their letter recognition improved significantly more than the children viewing letters and digits. We suggest that visual–motor integration that involves the fine-motor system is changing the way preschoolers perceive symbols, from mostly visual processing to integrating both visual and motor pathways. Previous work has shown that, indeed, handwriting practice serves to link visual and motor systems in the brain (Vinci-Booher, James, & James, 2016) more than typing practice. Our current findings suggest that perhaps any visually guided fine-motor practice will help children learn letters. Further, research has also shown that children with high letter naming scores also have high writing scores of both letters and digits and digit writing itself was a significant predictor of letter naming skill (Molfese, Beswick, Molnar, & Jacobi-Vessels, 2006). These works suggest that any visually guided fine motor skill may facilitate letter knowledge measures.

From previous work, however, we know that typing (another visually-guided action) does not facilitate letter knowledge to the same extent as writing by hand (Longcamp et al., 2005). We believe that key pressing for a young child does not require visual guidance of the fine motor system, but rather it requires visual guidance of the gross motor system. In typing, the entire hand and wrist is used; manual dexterity is not an essential element. Therefore, it is crucial that visual guidance of fine motor control is required for the facilitative effect to occur on the forced-choice recognition task.

The present results confirm that hand-printing facilitates letter knowledge and, further, that the facilitative effects are not reliant on practicing the same form that is tested. Future work will be required to determine to what extent the visually guided fine-motor practice must match the tested symbol. For example, do the symbols have to be alphanumeric? Or could drawing shapes also facilitate letter knowledge? Research has shown a strong correlation between performance on letter copying tasks and complex drawing tasks in 8–10 year old children, as well as greater similarities between writing and drawing fluency in children younger than 6, suggesting that drawing at the pre-school age might also promote emergent writing skills (Bonoti, Vlachos, & Metallidou, 2005; Adi-Japha & Freeman, 2001). Perhaps producing digits at this age range is similar to complex drawing, and would account for the similar increases in letter knowledge by children practicing letters and digits, suggesting that any form of complex drawing would show a similar increase in letter knowledge. Perhaps fine-motor skills such as finger drawing of symbols in sand would be just as facilitative. Interestingly, two studies found that 'writing' letters with stickers facilitated letter knowledge (Aram & Biron, 2004; Aram, 2006). These findings are important for preschool and early elementary curricula development, as hand printing with various instruments and forms may be more engaging for the young child than repetitive letter printing. In addition, if more efficient visual–motor integration resulting from practicing visually guided fine-motor tasks is a key factor, then we also must focus on teaching young children to increase visually guided fine-motor skill through activities that target the use of vision to control individual fingers. This point is supported by work showing that children with reading delays also have low fine motor skills (Iverson & Goldin-Meadow, 2005).

In short, we have shown that hand-production of alphanumeric forms facilitates letter knowledge, and does not require that the practiced form is the same as the tested form. We interpret this finding as demonstrating that the key factor in the facilitative effects that handwriting has on letter knowledge is the visually guided, fine-motor skill that is required for symbol production.

An interesting question that we did not address is whether practice writing symbols has a facilitative effect on other symbols in addition to letters. We believe that this is possibly the case given our previous work on teaching children novel scripts through writing, but this question is yet to be explicitly tested.

Facilitative effects are seen in a broader age range than previously shown

In Longcamp et al. (2005), only children in their older age group showed a facilitative effect of handwriting. The older children in that sample were 4.5 years of age on average while the younger group was 3.5 years on average. Here, we extended this age range up to 6 years old and found that handwriting increases letter knowledge in preschool- and kindergarten-aged children.

Letter knowledge assessment using various tasks

Understanding letters through visual inspection can be assessed in many different ways. Here we focused on three different aspects of letter knowledge: Letter naming, that requires matching a visual image to a stored label for that image; letter categorization, that only requires matching a visual image to another, similar image; and through a forced-choice recognition task that requires selecting a match to the target image from a group of non-matching alternatives. The naming task is arguably the most difficult of the three because it requires matching a visual image of a letter to a stored representation of that letter and its corresponding label. Our other two tasks did not require explicit naming. However, in this sample, letter naming was higher than the forced-choice task in both pre-and post-training. The letter sorting task, a form of categorization, required matching one image of a letter to that same letter presented in a different font. Thus, the children had to understand that a given target belonged to a given category and make a match based on visual similarity. This was the easiest task for these children, reflected by their higher mean scores both pre- and post-training. The forced-choice recognition task required matching a handwritten image of a letter to 4 alternatives that varied in their similarity to the target, which was the most difficult task for these children. In this task, there was a category match (same letter, but looks different) being the correct choice, but also 3 other similar looking alternatives: one of which was a reversal of the target, which is often a very difficult decision for children to make. It was only in this task that we saw significant differences between pre- and post-training scores as a function of training condition.

Writing letters facilitated performance in this task possibly because writing by hand trains the fine-motor system the correct orientation of a given letter. Although children in this study were not given feedback concerning the orientation of their letter and digit productions, we did observe that with increased writing practice, reversals did diminish. Thus, it is possible, although not explicitly tested here, that handwriting served to train children about letter reversals, which may have decreased a tendency to falsely select a letter reversal in the forced-choice task. This intriguing suggestion begs for additional research on the effects of writing of the perception of letter reversals.

Controlling visual exposure

It is quite difficult to equate the amount of visual exposure that a child has during handwriting to visual-only practice. This is often because when looking at a letter, a child will generally only look at it for a short amount of time and become disinterested. In contrast, when copying a letter, the child will often look at the model several times to accurately reproduce the form. This was the first study, to our knowledge, that equated the visual exposure time in our two groups by having our control group participate in an engaging ‘maze’ during which they saw the target symbol present for the whole time. We, therefore, were able to equate visual exposure during writing to that of the control group. This is important because previous facilitative effects of writing may have been simply due to a greater amount of visual exposure to the stimuli being learned—we know now that this is not the case. We did not, however, explicitly measure the amount of time a child spent looking at the symbol, only that the symbol was visible for the same amount of time. Further work should incorporate eye-tracking technology to further examine visual attention differences in these two conditions.

It is important to consider that some of our effects, or lack thereof, may have also been due to differences in attention during the two tasks. We intentionally designed the viewing condition to increase attention, to make it more similar to the writing condition in terms of effort and attention. Because we did not explicitly measure attention, however, this attempt may not have been successful. This is an issue with any study that compares active interaction with a stimulus to a more passive viewing condition and is very difficult to control. Thus, we cannot rule out that our interaction between writing and viewing is due to attentional differences in the two tasks. This point however, does not diminish the significance of the effect. If writing facilitates letter recognition due to greater attention during writing, then we could also conclude that engaging visual–motor systems also engages attention more than purely visual tasks. We are not adverse to this interpretation of these results and would encourage groups to explicitly test this aspect of handwriting and visual–motor interaction with stimuli in general.

Conclusion

In this simple empirical training study, we have shown that young children who learn symbols through handwriting develop better letter recognition than their peers who were exposed to symbols for the same amount of time but without producing them by hand. We also showed that even practicing digits by hand facilitates subsequent letter recognition, suggesting that visually guided fine-motor production of forms increases letter recognition in a general, rather than in a stimulus-specific manner. Although experimental parameters are difficult to control in a classroom setting, such studies are important in investigating possible interventions for early education. This particular finding contributes to our knowledge of the facilitative effects that early handwriting practice has on letter knowledge, an important pre-literacy skill.

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