BILINGUAL HANDWRITING DEVELOPMENT

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Abstract

Based on the importance of handwriting in academic and literacy development, this thesis examines the handwriting differences between monolingual and French-English bilingual second-grade students through the use of eye-tracking technology. A total of 23 students (12 monolinguals, 11 bilinguals) participated in the study, which consists of reading and writing a series of 24 English, French, and pronounceable nonsense words of varying lengths followed by three standardized tests that measure reading comprehension, spatial working memory, and vocabulary recognition. Eye-tracking videos were coded trial by trial for pen lifts, accuracy, and copying times. Though word length and word type did not significantly predict word score or Phase 1 duration, results indicated that children's motor continuity decreased as the words increased in length across all three of the word types. This effect varied between groups, such that monolinguals lifted their pens more than bilinguals, but not to a significant degree. Analyses also revealed that children spent longer times writing longer words, but this did not vary across the different word types. Though these results do not support significant differences between language groups, future research with an increased sample size can help validate these results and continue to explore differences based on language group.

Keywords: bilingualism, French, handwriting, literacy, child development

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Bilingual Handwriting Development

Even as technology continues to progress and change modes of communication, handwriting continues to be one of the fundamental skills that children learn as they develop. The basic skill has been shown to contribute to children's overall learning and academic success, even predicting how they perform in school and in the workplace (McCarroll & Fletcher, 2017). Because of the importance of this skill, studying the process of handwriting can reveal how automaticity in this skill contributes to child literacy. In order to understand how the brain integrates visual and motor coordination, we must look at the process of handwriting as a whole rather than focusing on the end result of handwriting. To do this, researchers have begun to employ the online method of eye-tracking to actively assess handwriting as participants read and copy stimuli (Maldarelli, Kahrs, Hunt, & Lockman, 2015; Fears & Lockman, 2018).

Until recently, the body of literature surrounding eye-tracking to study early literacy was very minimal and focused mainly on adults (Joseph, Nation, & Liversedge, 2013). Now, several studies have begun to look at how eye-tracking can be used to investigate typical literacy development, specifically the visual-motor integration that plays a role in the development process. As children get older, their eye-movements become more fine-tuned, partly due to their language development and partly due to their oculomotor development (Kandel & Valdois, 2006). Understanding the mechanisms behind their reading development can help inform educators and professionals and thus illuminate children's literacy development.

Visual Motor Integration

The use of eye-tracking techniques is fairly new in scientific research; however, this technology can provide great insight into reading and writing processes, particularly for children as they are just beginning to learn these skills. Eye-tracking allows researchers to actively monitor the way we read and comprehend text without disrupting the activity (Joseph et al., 2013). Saccades and fixations can reveal how information is processed and what reading difficulties are present such as comprehension and fluency errors (Joseph et al., 2013). Using eye-tracking technology can improve our awareness of how children develop, namely how they learn to read and write, two of the most basic foundations of literacy.

One of the first studies to use eye-tracking to study reading in children was done by Joseph and colleagues (2013) in attempt to understand how word frequency affects reading automaticity. After testing 8-year-old children and adults on a range of reading exercises, eye movement patterns and fixations were analyzed to reveal a direct effect of word frequency on word processing time. Children spent significantly longer times reading low-frequency words as compared to high-frequency words, which supports the idea that children's eye movements differ according to the linguistic characteristics of text (Joseph et al., 2013). As children age, their vocabularies will expand, and word frequency effects will change depending on the terminology they encounter. Studying the beginnings of this process can enhance understanding of how children's literacy development progresses.

The primary basis of the current study comes from two prior studies investigating the underlying mechanisms of children's handwriting via eye-tracking technology. The first of these studies, performed by Maldarelli and colleagues (2015), examined children's abilities to coordinate their motor, perceptual, cognitive, and linguistic skills during the writing process. Focusing on visual-motor integration, researchers used a series of letter and word copying tasks to compare the handwriting of children and adults. Participants were shown single letters, three-letter words, and three-letter nonsense words and asked to reproduce what they saw. Both pronounceable and non-pronounceable nonsense words were used to understand if children read letter strings as one lexical chunk or letter by letter. Based on the results of this study, age differences showed that children spent more time copying and had more fixations than adults. Additionally, the increased cognitive demands for three-letter words compared to single letters resulted in longer copying times and an increase in writing interruptions and refixations on the stimulus. Finally, children and adults showed more fixations on the nonsense words compared to real words, showing their ability to differentiate stimuli linguistically (Maldarelli et al., 2015).

Fears and Lockman (2018) built upon Maldarelli's work in their study by assessing children's visual-motor coordination of handwriting through the copying of familiar and unfamiliar letter forms. With the use of head-mounted eye-tracking methods, researchers analyzed the automaticity of children's handwriting in the form of copying times, fixations, and motor continuity defined by pen lifts. Copying times were divided into two phases: the information gathering phase, which occurred prior to writing, and the writing phase. From the sample of 40 children, the results showed the children performed less efficiently on the unfamiliar Cyrillic symbols than the familiar English letters as evidenced by an increase in re-fixations for the Cyrillic symbols (Fears & Lockman, 2018). These findings support the idea that children are more efficient in writing familiar letters compared to symbols that are unfamiliar to them.

Bilingualism

Although previous eye-tracking studies have analyzed both reading and writing processes in children, the focus has been centered on monolingual children. Few studies to date have focused on bilingual children; however, the population of bilingual children in the world is continuing to grow and expand. In some schools, the number of bilingual students and those from linguistically diverse backgrounds outnumber their monolingual counterparts (Schester & Cummins, 2003). Nevertheless, the scope of what is known about this particular population is still lagging behind.

In order to begin to understand this unique population, we must first define bilingualism. The term "bilingualism" has become a part of common speech, but many different definitions exist to explain the meaning of bilingualism. For example, Lacroix (2008) defines bilingualism as "a proficiency in at least one of the four areas of language: speaking, listening comprehension, reading and writing" (p. 6) To be bilingual requires proficiency in two languages, usually with the ability to speak and understand both languages but often with some preference towards one or the other. For bilingual children, they may use different languages in school and at home, but they should be able to use both languages to communicate. For the purposes of the present study, bilingualism will be measured on a spectrum, due to the varying degrees of fluency that exist for bilingual children in the US.

Due to their unique language abilities, understanding how bilingual children learn and develop can provide insight into the benefits of multiple language learning as well as the challenges that may arise. Researchers have investigated this bilingual advantage through multiple techniques such as standardized testing and cognitive assessments.

Berens and colleagues (2013) researched differences between Spanish-English bilingual children and English monolingual children, specifically focusing on bilingual children who learned Spanish and English in succession compared to those who learned the two languages at the same time. Based on the different reading comprehension and decoding tasks performed, they discovered that simultaneous language learning may lead to bilingual reading advantages (Berens, Kovelman, & Pettito, 2013).

In another study by Kandel and Valdois (2006), the spelling acquisition of French- and Spanish-speaking monolingual children was analyzed and compared to that of French-Spanish bilingual children. The study used a word-copying task via a digitizer connected to a computer that examined the motor path of the participants. Researchers then evaluated their performance based on gaze lift analysis. Their results revealed that French participants preferred letter and syllable-sized units whereas their Spanish counterparts copied words as whole orthographic units. Interestingly, the bilingual children performed similarly to the monolingual children in that they copied French words in smaller lexical units and used larger units for Spanish words (Kandel & Valdois, 2006). This study provides evidence for how differences among languages are related to differences in how children perceive and copy words.

While these studies provide a basis of how different languages can influence child literacy, very few have used eye-tracking technology to examine the development of reading and writing skills in bilingual children. Whitford and Joanisse (2018) were some of the first to research bilingual children's reading performance based on their eye movements. In their study, English monolingual children and French-English bilingual children aged 7 to 12 were given several paragraphs to read while using a desktop-mounted eye-tracker. Their eye movements were then analyzed globally (text-level) and locally (word-level) to show several differences between the bilingual and monolingual groups. They discovered that despite having similar levels of reading comprehension, bilingual children produced slower reading rates, more saccades, and more fixations than monolingual children when reading in English (2018). Whitford and Joanisse also assessed the validity of the "weaker links hypothesis," which claims that greater exposure to words leads to greater lexical quality and accessibility (Gollan, Montoya, Cera, & Sandoval, 2008). They found that bilingual children had slower recognition times due to their divided language use and thus less exposure to the same words as monolinguals (2018). This study provides an interesting look at bilingual children's reading performance and the ways in which it differs from that of monolingual children.

This "weaker links hypothesis" initially proposed by Gollan and colleagues (2008), was examined in their study of bilingualism and aging. They used picture naming as a means of testing language production in monolingual and Spanish-English bilingual participants. From their analyses, they found that bilingual participants were more likely than monolingual participants to show performance differences on high-frequency and low-frequency words. While both groups recognized the highly frequent words more quickly than the less frequent words, this difference was larger for the bilingual group. In a second experiment, older (age M=76.0) and younger (age M=19.3) monolinguals as well as older (age M=74.9) and younger (age M=19.3) bilinguals were tested. They discovered aging differences, such that older bilinguals performed more slowly than the younger bilinguals when tested on high-frequency words in Spanish; however, this difference was not observed in low-frequency words, suggesting that these frequency effects fade over time (Gollan et al., 2008). Based on this study, we can infer that bilinguals' vocabulary differences may affect their recognition abilities, but this disparity is attenuated over time.

The Current Study

Due to the gap in the literature regarding bilingual handwriting studies, the current study examines differences between the handwriting of monolingual and French-English bilingual second grade students when copying English words, French words, and pronounceable nonsense words. This age group is younger than those typically looked at in bilingual eye-tracking studies; however, they can provide an important look at the development of reading and writing skills. With the use of eye-tracking technology, this study will investigate the effect of children's language knowledge on their ability to read and copy words of varying lengths in each language. Both the monolingual and bilingual participants will be presented simple French and English words as well as pronounceable nonsense words in order to explore the effect of stimulus familiarity on writing performance. While the English and French words will serve to differentiate between the bilingual and monolingual groups, the nonsense words are used as a control that neither group should recognize. Based on prior research, children are expected to perform better on words that they recognize than on the nonsense letter strings (Maldarelli et al., 2015; Fears & Lockman, 2018). We expect to see differences between the monolingual and bilingual participants' handwriting in terms of copying times and pen lifts. Pen lifts, which serve as a measure of motor continuity, are measured each time the participant lifts the pencil from the paper during writing. Copying times, which are divided into durations of information gathering (Phase 1) and writing (Phase 2), are assessed trial by trial. These differences will serve to demonstrate how bilingual children's ability to recognize both languages may affect the visual and motor strategies they deploy when reading and writing words.

Method

Participants

The sample consists of 23 second grade students: 12 monolinguals (English only) and 11 bilinguals (French and English) recruited from elementary schools in New Orleans. Bilingual participants attended a French immersion school, such as École Bilingue de la Nouvelle-Orléans or the International School of Louisiana, for at least one year to ensure that they have the capability to read and write in French. In order to assess participants' knowledge of the language(s), a parental guardian was asked to complete the Home Literacy and Bilingualism Questionnaire, which was created as a means of understanding the participant's upbringing and experience at home and in school. The questionnaire includes items similar to the Language and Social Background Questionnaire (LSBQ), which measures second language skills on a continuous scale. Some of the questions in the LSBQ include when the child began learning the language, whether or not the language is spoken at home, and a rating of their level of proficiency from beginner to native speaker (Anderson, Mak, Keyvani, & Bialystok, 2018) (see Appendix A).

The study took place at the Infant and Toddler Development Project lab space located at Tulane University Square. Approval for the study was received from the Tulane International Review Board. Parents provided written consent for each child that participated, and they were offered a $10 gift card or a child's t-shirt in compensation for their participation.

Design

This study used a 2x3x4 mixed-factor design. Independent variables were language exposure, word length, and word type. Language exposure, a between-subject factor, was divided into the two levels of monolingual and bilingual participants as determined by participants' responses to the Home Literacy and Bilingualism questionnaire. The two within-subject factors, word length and word type, were based upon the copying stimuli given to all participants. Word type consisted of three levels: French words, English words, and pronounceable nonsense letter strings. To assess the effect of word complexity, word lengths included 3-letter, 4-letter, 5-letter, and 6-letter words. Each participant was given two exemplars of each word length x word type combination for a total of 24 total trials randomized for each participant.

Procedure

Apparatus

The first part of the study included the use of an eye-tracking device to record the participants' visual and motor skills as they read and copied each word shown. The eye-tracker used two cameras: a scene camera that recorded the word being copied and the child's writing movements, and an infrared camera that recorded their eye movements (Positive Science). After introducing the participant and their parent or guardian to the eye-tracking technology, the eye-tracker was comfortably placed on the child. Following the eye-tracking procedures outlined by Fears and Lockman, each child was instructed to hold their head still while moving their eyes to each of 12 equally spaced calibration points to obtain a smooth and accurate calibration. This process was repeated after the word copying task as a secondary means of verification. The eye and scene videos were recorded using

PSLiveCapture software and processed with Yarbus software to produce a scene video which also indicated the direction of the child's gaze (Fears & Lockman, 2018).

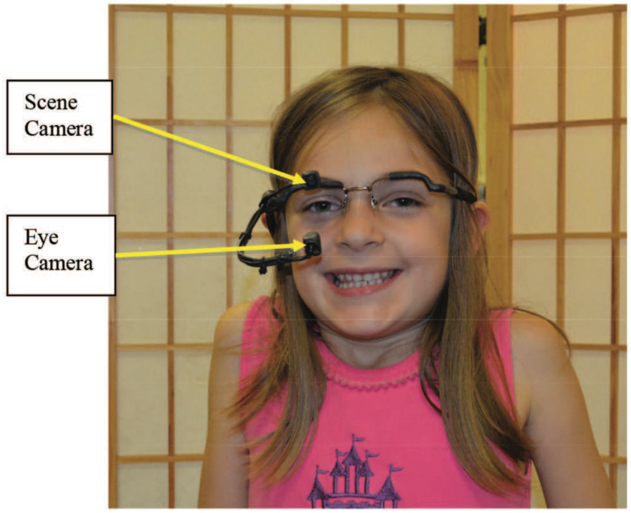

Figure 1. Child wearing eye-tracker (Positive Science).
Signed consent was received for the publication of this photo.

Stimuli

After calibration, the word copying task began with a practice trial to familiarize participants with the format of the task. Participants then copied the 24 target words, consisting of 8 French words, 8 English words, and 8 pronounceable nonsense words, in random order. To control for word frequency effects, both the French and English words were chosen from word corpora based on highly frequent words used by first grade students (L'été, Sprenger-Charolles, & Colé, 2004; Zeno, Ivens, Millard, Duvvuri, & Rothkopf, 1995). Two 3-letter, 4-letter, 5-letter, and 6-letter words were chosen from each language to account for differences in word complexity. One word of each length from each language was scrambled to create 8 pronounceable nonsense words to act as a set of copying stimuli unrecognizable across all participants, regardless of language skill (see Table 1).

Table 1

Stimulus Words

	French	*English*	*Nonsense*
3-letter	Coq	Bed	Odg
	Nez	Dog	Qoc
4-letter	Loup	Frog	Gorf
	Pied	Kite	Polu
5-letter	Avion	Bread	Lufer
	Fleur	Mouth	Humot
6-letter	Chaise	Turtle	Oirsus
	Souris	Window	Trelut

Additional Measures

Table 2 describes the three tests that were given in random order following the eye-tracking task. The four-alternative forced choice picture test assessed participants' comprehension of the given French and English words that were copied. Using a format adapted from the Peabody Picture Vocabulary Test, images were organized and arranged into 2x2 squares with the correct answer choices appearing an equal number of times in each of the four positions (Dunn, 2007). Images other than the target image were randomized by category, such that the distractor images on each page represented different types of vocabulary words (e.g. foods, animals, household objects). Word order was randomized for each participant.

The Corsi Block-Tapping Test was used to assess spatial working memory as a control between the two groups. Participants were asked to repeat increasing sequences of block tapping in order to control for the effect of spatial working memory on word copying (Corsi, 1972; Fischer, 2001). The Woodcock Johnson Letter-Word Identification (LWI) subtest was used to control for English language reading level across the monolingual and bilingual groups (Schrank, McGrew, & Mather, 2014). In total, the entire testing session lasted about 30 to 45 minutes per child.

Table 2

Experimental Session Tasks

Task	*Description*	*Scoring*
Word Copying	Participants are asked to copy 24 words (8 French, 8 English, and 8 nonsense) while wearing eye-tracking glasses.	Scoring is based on handwriting errors and letter order. Other factors include pen lifts.
Picture Test	For each of the French and English words, participants are shown 4 picture choices and asked to pick the one that they think best corresponds to the word.	Participants are scored as correct (0) or incorrect (1) depending on the picture that they choose.

Corsi Block-Tapping Test	The researcher taps the blocks in a certain order and asks the participant to tap the same blocks in the same order. Sequences are increased to test digit span.	Participants' scores are determined by the longest sequence of correct block strings they achieve.
Woodcock Johnson LWI	Participants are shown a series of words and asked to read them aloud. They continue until the participant misses 6 words in a row.	Scores are based on how many words the participants read correctly.

Dependent Measures

The visual-motor process of handwriting for each participant was analyzed with respect to the following dependent measures: copying time, accuracy, and pen lifts (see Table 3). Copying times were determined by the trial duration, which began when the target word was made visible to the participant and ended when he or she lifted their pencil at the end of copying. Similar to the procedures used by Fears and Lockman (2018), the trial duration in this study was separated into the information gathering phase (Phase 1) and the writing phase (Phase 2). While the information gathering phase began as soon as the stimulus was revealed, the writing phase did not start until the participant began writing on the page. Within the writing phase, pen lifts were assessed frame-by-frame using the

Datavyu coding system (http://www.datavyu.org). Pen lifts, defined by each moment that the participant lifted the pencil from the paper, were used to measure motor continuity. Approximately 20% of the eye-tracking videos were double coded as a means of interrater reliability. Intraclass Correlation Coefficient estimates were calculated, revealing moderate reliability for writing score (ICC = .561) as well as excellent reliability for pen lifts (ICC = .986), Phase 1 durations (ICC = .981), and Phase 2 durations (ICC = .998).

Table 3

Dependent Measures

Writing duration	*Looking duration*	*Writing score*	*Handwriting errors*	*Pen lifts*
For each word, the writing duration starts when the participant's pencil touches the page and ends on the last pen lift.	The time spent looking at the stimulus prior to writing is calculated by subtracting the writing duration from the total trial time.	Each word is scored as correct (1) or incorrect (0) dependent upon handwriting errors that were made. Cursive trials are excluded.	Errors, such as letter reversals or incorrect letter order, are recorded letter by letter.	The number of pen lifts per word is determined by each time the participant's pencil leaves the page. Cursive trials are excluded.

Results

The study's findings are reported in two sections. In the first part, average standardized test scores are examined in relation to dependent writing measures and group differences. Three-way split-plot ANOVAs on pen lifts and writing time with follow-up analyses of significant effects with Bonferroni post-hoc testing are reported next.

Standardized Test Scores

Correlation analyses were used to investigate the relation between the standardized test scores and the dependent measures of writing performance. Results are presented in Figure 2.

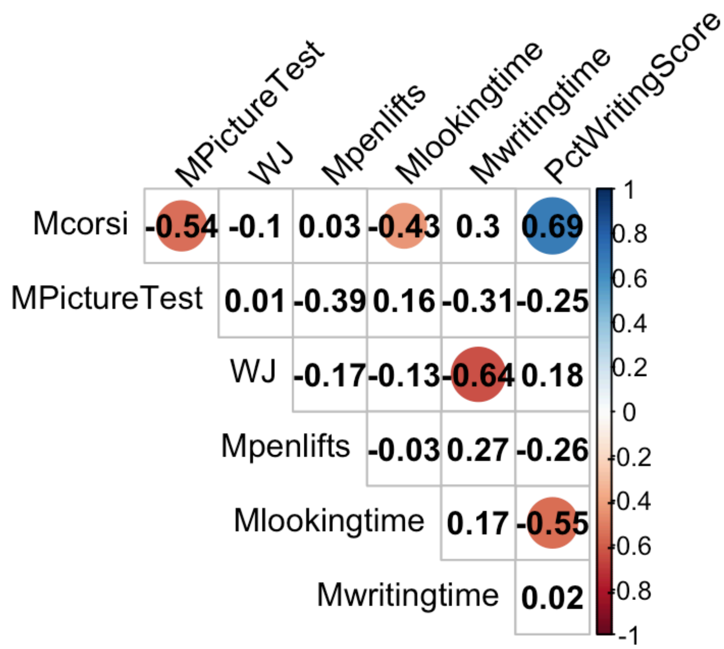

Figure 2. The Relation Between Standardized Test Scores and Writing Performance (Writing score percentages were used to exclude trials written in cursive. A total of 14 trials were excluded.)

Results of the Pearson correlation indicated several statistically significant relations. The correlation between participants' writing scores and scores on the Corsi Block-Tapping Test, $r(22) = +0.69$, $p < .05$, was statistically significant such that spatial working memory is positively related to writing performance. Participants' writing scores were also negatively correlated with looking time (the information gathering during Phase 1) $r(22) = -0.55$, $p < .05$, which suggests that longer looking durations are associated with decreased writing performance. Results also indicated a negative relation between looking time and Corsi scores, $r(22) = -0.43$, $p < .05$, which suggests that children who looked longer at the stimuli during Phase 1 performed worse on the Corsi Block-Tapping Test. Corsi scores were also negatively correlated with scores on the Picture Test, $r(22) = -0.54$, $p < .05$, suggesting that reading comprehension and spatial working memory may be negatively related. The correlation between scores on the Woodcock Johnson LWI and mean writing time, $r(22) = -0.64$, $p < .05$, was also statistically significant such that reading comprehension is negatively related to the average duration spent writing each word.

To further analyze the relations among standardized measures, correlation analyses were performed within each language group. Results are presented in Figure 3. These correlations should be interpreted with caution given the small sample size of each group (N = 12 monolingual; N = 11 bilingual).

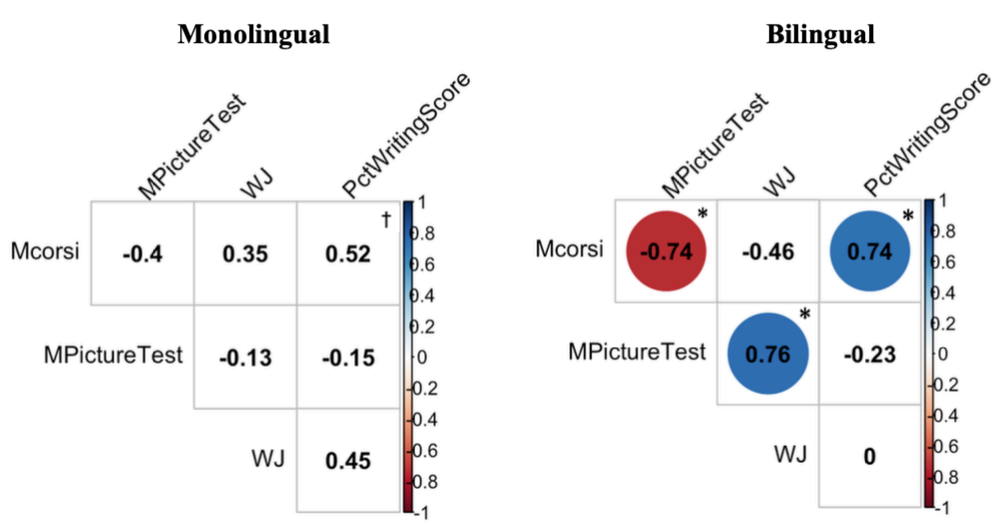

Figure 3. The Relations Among Standardized Test Scores by Language Group (* indicates a significance of $p < .05$; † indicates a significance of $p < .1$)

Among monolingual participants, no significant correlations were discovered; however, a trending relation was found between writing scores and Corsi scores, $r(10) = +0.52$, $p < .1$, consistent with the significant relation found in the bilingual group, $r(9) = +0.74$, $p < .05$. Results from the bilingual group also indicated a strong positive relation between scores on the Woodcock Johnson LWI and scores on the Picture Test, $r(9) = +0.76$, $p < .05$. Conversely, the monolingual group showed a negative relation that may be due to decreased performance on the Picture Test associated with knowledge of only one of the languages tested. The bilingual group also showed a significant negative relation between Picture Test scores and scores on the Corsi Block-Tapping Test, $r(9) = -0.74$, $p < .05$; however, a larger sample is needed to determine if this finding is reliable.

Pen Lifts

Three-way split-plot ANOVAs were used to analyze the effects of word length, word type, and language group on the dependent measures. Table 4 presents the ANOVA table measuring effects on pen lifts. These effects are further visualized in Figure 4.

Table 4

Within-Subjects Effects of Word Length and Word Type on Pen Lifts

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Length	632.527	2.365	267.499	627.116	.000***
Length*Group	.520	2.365	.220	.515	.631
Error (Length)	21.181	49.657	.427		
Type	5.305	1.993	2.662	12.692	.000***

Type*Group	.178	1.993	.089	.426	.655
Error (Type)	8.777	41.843	.210		
Length*Type	31.767	2.329	13.637	13.022	.000***
Length*Type*Group	2.242	2.329	.963	.919	.418
Error (Length*Type)	51.231	48.918	1.047		

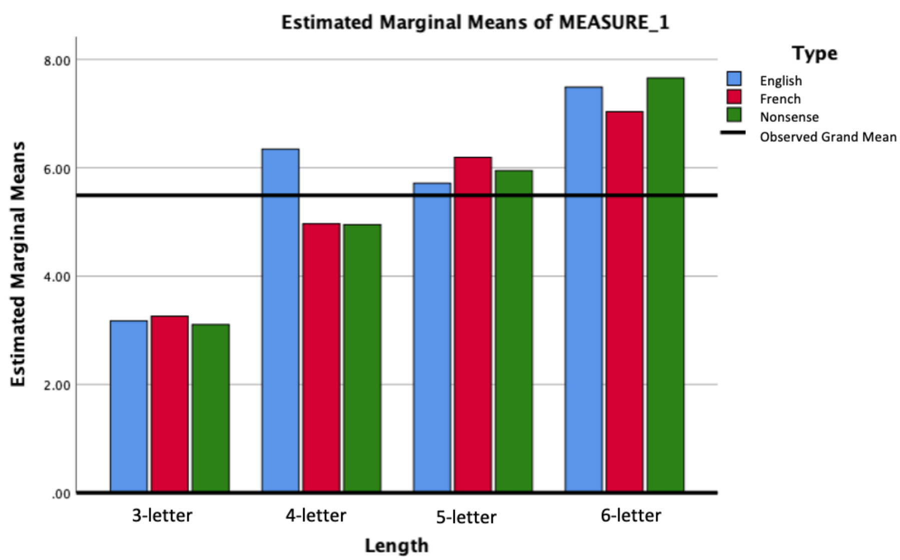

Figure 4. The Effect of Word Length and Word Type on Pen Lifts

When measuring pen lifts, the split-plot ANOVA revealed significant main effects for word length, $F(2.365, 49.657) = 627.12$, $p < .001$, and word type, $F(1.993, 41.843) = 12.69$, $p < .001$, which were qualified by a Length x Type interaction, $F(2.329, 48.918) = 13.02$, $p < .001$. To further understand this interaction, 1-way ANOVAs were run for each word type with word length (3-, 4-, 5-, 6-letter words) as the independent variable. For English words, the average pen lifts for each word length differed significantly from each other as expected and increased with length, except that participants made significantly fewer pen lifts on 5-letter words (M = 5.72) than on 4-letter words (M = 6.35). For French and nonsense words, the 1-way ANOVAs revealed that average pen lifts for each word length were significantly different from each other and followed the expected direction, increasing with the number of letters in a word ($p < .05$) (see Table 5).

Table 5

Mean Pen Lifts Per Word Length

Word Type	*Word Length*	*Mean*	*Std. Error*
English	3-letter	3.174	.081
	4-letter	6.348	.102
	5-letter	5.717	.088
	6-letter	7.500	.169
French	3-letter	3.261	.108
	4-letter	4.978	.111
	5-letter	6.196	.237
	6-letter	7.043	.133
Nonsense	3-letter	3.109	.083
	4-letter	4.957	.180
	5-letter	5.957	.108
	6-letter	7.652	.073

The group effect on pen lifts (see Table 6) was not significant, $F(1, 21) = 9704.45$, $p = .076$, but the average number of pen lifts for the monolingual group (M = 5.59) was larger than the number of pen lifts for the bilingual group (M = 5.38) (see Appendix B).

An increased sample size would provide a stronger test of the reliability of this language group effect.

Table 6

Between-Subjects Effects of Word Length and Word Type on Pen Lifts

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
(Intercept)	8292.138	1	8292.138	9704.453	.000
Group	2.971	1	2.971	3.477	.076
Error	17.944	21	.854		

Writing Duration

An additional split-plot ANOVA measuring writing duration showed a significant main effect for word length, $F(1.833, 38.497) = 24.28$, $p < .001$, such that participants took longer average durations to write words with an increased number of letters (see Tables 7-8).

Table 7

Mean Writing Durations by Word Length

Length	*Mean*	*Std. Error*
3-letter	5649.650	3780.935

4-letter	6185.852	701.976
5-letter	7455.532	623.169
6-letter	8415.887	691.696

Table 8

Within-Subjects Effects of Word Length and Word Type on Writing Duration

Source	*df*	*F*	*Sig.*
Length	1.833	24.281	.000 ***
Length*Group	1.833	.512	.588
Error (Length)	38.497		
Type	1.889	1.107	.338
Type*Group	1.889	.677	.506
Error (Type)	39.667		
Length*Type	2.975	.991	.403
Length*Type*Group	2.975	.659	.579
Error (Length*Type)	62.465		

To further analyze the significant main effect of length on writing duration, Bonferroni-adjusted pairwise comparisons were run within the split-plot ANOVA. The comparisons as displayed in Table 9 showed that average writing durations increased as words increased in length. Additionally, average writing durations for each word length differed significantly from each other ($p < .05$) except for 3-letter and 4-letter words ($p = .681$).

Table 9

Pairwise Comparisons of Word Length on Writing Duration

Word Length	*Comparison Word Length*	*Mean Difference*	*Std. Error*	*Sig.*
3-letter	4	-536.203	324.616	.681
	5	-1805.883	501.883	.010 **
	6	-2766.237	416.308	.000 ***
4-letter	3	536.203	324.616	.681
	5	-1269.680	306.819	.003 **
	6	-2230.035	280.260	.000 ***
5-letter	3	1805.883	501.833	.010 **
	4	1269.680	306.819	.003 **
	6	-960.355	259.354	.008 **
6-letter	3	2766.237	416.308	.000 ***
	4	2230.035	280.260	.000 ***
	5	960.355	259.354	.008 **

(** $p < .05$; *** $p < .01$)

A significant group effect on writing duration was not obtained, ($p = .344$), but the average writing duration for the bilingual group (M = 7606.44 ms) was larger than the average writing duration for the monolingual group (M = 6247.02 ms) (see Appendix B).

Discussion

The purpose of this study was to determine differences in monolingual and bilingual children's handwriting when copying French, English, and pronounceable nonsense words. Handwriting samples were analyzed for motor continuity as measured by pen lifts and for copying times during phases of looking and writing. The additional standardized tests were used to examine reading level and spatial working memory across participants and to assess language knowledge via vocabulary recognition.

Pen Lifts

Based on the results, word length, word type, and the interaction of word length and word type were all found to have significant effects on the number of pen lifts used by each participant. Overall, the bilingual group used an average of 5.38 pen lifts per word while the monolingual group used an average of 5.59 pen lifts per word, suggesting a slight difference among groups but not enough to have a significant effect (p = .076). With a larger sample size, this language group effect can continue to be examined. Following further analyses, the average number of pen lifts per word was found to increase as the words increased in length, signifying a decrease in motor continuity due to increased word length. This was the case for all three of the word types (English, French, and nonsense), which is not surprising due to the need to lift the pen more for each additional letter. The one exception was for 4-letter and 5-letter English words in which more pen lifts were made for the shorter words. This unusual finding can be explained as a function of the specific words such that more pen lifts were needed for the letters in the 4-letter words (i.e. "kite") than those in the 5-letter words (i.e. "bread"). Controlling for word length could provide interesting comparisons in terms of pen lifts and how they differ across different types of words.

Phase 1 Duration

During testing, trials were separated into two phases: the information gathering phase (Phase 1) which occurred prior to writing when participants gathered information about the stimulus, and the writing phase (Phase 2) which began when the child started writing and ended with the last pen lift. Results from the correlation analyses revealed that higher writing scores were related to shorter Phase 1 durations, suggesting a link between reading and writing. A possible explanation for this relation may be the ability of participants to recognize the familiar and unfamiliar stimuli. As indicated in Fears and Lockman's study, stimulus familiarity plays an important role in visual processing (2018). After further analysis, no significant effects of word type or word length on Phase 1 duration were found. Additionally, language group did not significantly affect Phase 1 duration in this study, contrary to Whitford & Joanisse's findings that bilingual participants had slower recognition times than monolinguals (2018). Due to the limited sample size of this study, further research is needed to continue examining the role of stimulus familiarity in reading and writing.

Phase 2 Duration

This connection between reading and writing is also shown by the relation between Phase 2 durations and scores on the Woodcock Johnson LWI Test. Correlation analyses showed that higher levels of reading comprehension are related to shorter writing durations. This association can also be explained in terms of stimulus familiarity such that participants are more likely able to read and write familiar words without interruption as compared to unfamiliar words; however, results from the split-plot ANOVA found word length as the only significant predictor of Phase 2 duration. Further analyses explained that the average writing duration significantly increased as words increased in length except for 3-letter and 4-letter words. This discrepancy is likely due to the less frequent letters "q" and "z" appearing in these shorter words. Although target words attempted to reduce word frequency effects by utilizing highly frequent words from word corpora, this did not account for less commonly used letters of the alphabet. Nevertheless, the effect of word length shows us that longer words tend to take longer durations to write, which is consistent with Maldarelli's findings in her handwriting study (2015).

Standardized Test Scores

Based on the results of this study, participants' scores on the Corsi Block-Tapping Test, Woodcock Johnson LWI, and Picture Test reveal interesting relations among these standardized measures and the measures of writing performance. The Corsi Block-Tapping Test assesses participants' digit span and can be used to measure spatial working memory; therefore, the relation between Corsi scores and writing score shows that spatial working memory is strongly associated with writing performance for both groups, especially the bilingual group. This suggests that spatial working memory plays an important role in the writing process such that children use their spatial working memory to remember the spatial form of the word being copied. Visual spatial skills are an important part of the Corsi Block-Tapping Test, which explains why participants with higher Corsi scores are likely to have shorter looking durations as well. During the experimental task, looking duration, which occurs prior to writing, is used to gather information about the spatial form of the stimulus word in order to prepare to complete the assigned task; therefore, spending longer amounts of time gathering information suggests a lack of familiarity and difficulty completing the task. Surprisingly, Corsi scores are negatively related to scores on the Picture Test; however, a larger sample is needed to determine if this finding is reliable.

The four-alternative forced choice picture test is used to measure participants' language knowledge as a means of vocabulary recognition. Scores on the Picture Test were found to have a strong positive relation with scores on the Woodcock Johnson LWI for the bilingual group; however, this relation was negative for the monolingual group. Not surprisingly, due to monolingual participants' expected lack of familiarity with French words, their performance on the Picture Test was reduced and therefore negatively related to Woodcock Johnson LWI scores. The positive correlation for bilingual participants suggests that higher levels of English reading comprehension are associated with increased vocabulary recognition of English and French words. Due to ongoing data collection, further analyses on these standardized measures will be run once a full sample is recruited.

Limitations and Future Research

Due to social distancing and stay-at-home restrictions enforced by the national government in response to the outbreak of COVID-19, data collection was unable to be completed for this study. In order to further investigate the differences between monolingual and bilingual children's handwriting, a larger sample is needed. Fortunately, the study is planned to continue for an additional year and data collection will resume. Additional measures will also be included, namely lookbacks coded from the eye-tracking videos which will be used to measure reading fluency. This measure, in combination with the pen lift data, will help to explain the role of stimulus familiarity when writing.

Bilingualism will also be coded as a continuous variable to expand upon the analysis of language group effects.

Eye-tracking technology is associated with limitations as well due to the stillness and cooperation of participants required for calibration and subsequent copying. In order to encourage more natural writing, participants were asked to write in their normal handwriting; however, this created several coding issues due to trials being out of view and the use of cursive writing. Trials written in cursive were later excluded from analysis to keep coding consistent across participants.

Conclusion

Handwriting is a fundamental skill in the academic development and literacy of children; therefore, it is important to understand what factors affect handwriting performance. Especially due to the growing population of bilingual speakers, understanding these factors can reveal significant differences about how they differ across languages. In this study, writing performance was examined through pen lifts, accuracy, and durations spent writing and looking at the stimuli. These measures were all analyzed as outcomes of the predictors word length and word type. Although no relations were found with accuracy and looking duration, the findings revealed that word length affected writing duration such that longer words took longer times to write. Additionally, it was found that the interaction of word length and word type influenced the number of pen lifts used such that more pen lifts were used on longer words across all three of the word types. Though there were no significant group effects found based on language, the two groups did show differences in terms of pen lifts. Due to the limited sample size of this study, future research can help support these findings and consider further differences among language groups.

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Appendix A

HOME LITERACY AND BILINGUALISM QUESTIONNAIRE

How many years has your child attended daycare? _________

How many years of preschool or pre-kindergarten has your child completed? _________

What school is your child currently in, or beginning, this school year? _________

When did (or does) the school year start (mm/dd/yyyy)? _________

What grade is your child currently in, or beginning, this school year? ___________

How many years of kindergarten has your child previously completed? ___________

Is or has your child been homeschooled for grades K-12? YES ______ or NO______

What lowercase letters and numbers can your child recognize and name? (Circle)

a b c d e f g h i j k l m n o p q r s

t u v w x y z 0 1 2 3 4 5 6 7 8 9

What lowercase letters and numbers can your child write correctly? (Circle)

a b c d e f g h i j k l m n o p q r s
t u v w x y z 0 1 2 3 4 5 6 7 8 9

Are there any letters/numbers that are especially difficult for your child to write?
What is the highest number your child can count to? ___________

Does your child have a handwriting workbook? If so, what is the name(s)?

Instructions: Please complete the following questionnaire, answering all questions. This questionnaire will take approximately 10 minutes to complete.

In the past month, how frequently did your child engage in the following activities <u>at home</u>?

Activity	Almost Never	Rarely (1-3 times per month)	Occasionally (once per week)	Frequently (3-4 times per week)	Almost Daily	N/A
1. Identifying names of written numbers						
2. Playing with number fridge magnets						
3. Sort things by category (e.g., size, color or shape)						
4. Counting objects						
5. Counting down (10, 9, 8, 7. . . .)						
6. Learning simple arithmetic (i.e., 2 + 2 =4)						
7. Printing numbers						
8. Picking up sticks, objects, etc.						
9. Drawing or coloring with pencils						
10. Drawing or coloring with crayons						
11. Drawing or coloring with markers						
12. Playing musical instruments						
13. Painting						
14. Talking about money when shopping (e.g., “Which Costs More")						
15. Measuring ingredients when cooking						
16. Identifying names of written alphabet letters						

17. Identifying sounds of alphabet letters						
18. Playing with puzzles						
19. Fitting objects into holes						
20. Being timed						
21. Using handwriting workbooks						
22. Playing with calculators						
23. Making collections						
24. Threading beads						
25. "Paint-by-number" activities						
26. Building with construction sets (Lego, Duplo, Megablocks, etc.)						
27. Tying shoes						
28. Playing with clay (e.g., "Playdoh")						
29. "Connect-the-dot" activities						

Does your child speak another language? Yes______ or No_______

What language(s)? ____

In what contexts? (Home, school, tutoring…)

____

What is their proficiency? (Please circle):

Beginner **Intermediate** **Advanced** **Native Speaker**

<u>If your child is NOT bilingual in French</u>, please complete the following questions as well:

Does your child take French classes in school? Yes _____ or No _____

If yes, for how many years? ___________

Are there any other ways that your child is exposed to the French language? (e.g. language apps, tutoring, etc.)

____

____

<u>If your child is bilingual in French</u>, please complete the following questions as well:

Age when your child began acquiring French: _____________

Age when your child began reading in French: ____________

Age when your child began writing in French: ____________

Is French spoken in the home? Yes ______ or No______

If yes, how many family members speak French? __________

Please list the number of years and months that your child has spent in each of the following language environments:

	Years	Months
A country where French is spoken		
A family where French is spoken		
A school environment where French is spoken		
Other context(s) (please specify)		

In a typical week, please rate how often your child engages in the following activities **<u>in French</u>**:

Activity	Almost Never	Rarely (1-3 times per month)	Occasionally (once per week)	Frequently (3-4 times per week)	Almost Daily	N/A
1. Speaking French						
2. Reading in French						
3. Writing in French						
4. Listening to music in French						
5. Watching TV in French						
6. Interacting with friends in French						
7. Interacting with family in French						

Appendix B

Means of Standardized Test Scores

Group		Corsi	Picture Test	WJ LWI	Pen Lifts	Looking Time	Writing Time	Writing Score
Monolingual	Mean	4.83	.714	52.83	5.59	1938.61	6247.02	97.57
	SD	.616	.121	8.06	.225	872.94	2224.88	2.79
Bilingual	Mean	4.55	.909	46.18	5.38	2403.59	7606.44	96.08
	SD	.960	.113	10.56	.307	1169.30	4283.77	5.75
Total	Mean	4.70	.807	49.65	5.49	2160.99	6897.18	96.86
	SD	.794	.152	9.73	.281	1029.03	3361.30	4.42