Connections between Fingerspelling and Print: The Impact of Working Memory and Temporal Dynamics on Lexical Activation

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Abstract
Recently there has been a renewed interest in characterizing the role of fingerspelling for deaf readers. The present study takes a step back and creates a theoretical foundation for investigating similarities between fingerspelling and print decoding in hearing signers. In this way, we can probe the constraints of temporal processing and memory on L1 orthography and the processing of L2 fingerspelling. Using a cross-modal priming paradigm, the role of orthography and phonology in print and fingerspelling word recognition was investigated. Results indicate significant inhibition in target retrieval when the prime was fingerspelled but not when it was presented in print. It was hypothesized that inhibition was due to either recoding or prime temporal dynamics. Hearing nonsigners were tested with serially or simultaneously presented print to determine the role of recoding and temporal dynamics. The results suggest that: (1) difficulties in

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processing fingerspelling for L2 learners might arise from recoding back into an L1 orthographic representation; (2) working memory abilities may reduce inhibition caused by recoding in L2 learners; (3) serial presentation of an orthographic code, either manual or visual, reduces priming effects; and (4) letter position differences provide evidence of depletion of activation over time.

Deaf students have scored lower than their hearing counterparts on literacy tests for decades; their median reading level upon high school graduation is equivalent to the fourth grade (Traxler 2000). Studies have debated whether phonemic awareness (Ehri et al. 2001; Liberman and Shankweiler 1985; Snow, Burns, and Griffin 1998), phonological awareness (Paul, Wang, Trezek, and Luckner 2009; Wang, Trezek, Luckner, and Paul 2008), signing ability (Mayberry, del Guidice, and Lieberman 2011), articulatory mechanisms (Hirsh-Pasek and Treiman 1982), visual codes (McQuarrie and Parrila 2009), or orthographic competence (Miller 2004) should be targeted in order to improve deaf reading. Researchers have recently begun reinvestigating fingerspelling as an alternative code; however, only a relatively small number of these studies have investigated the role of fingerspelling in literacy. Previous studies have examined the parsing of fingerspelling (Emmorey and Petrich 2011; Patrie 1990, 1992), acquisition of fingerspelled vocabulary (Happtonstall-Nykaza and Schick 2007), and identification, matching, and spelling/writing of fingerspelled words (Puente, Alvarado, and Herrera 2006). The current study is a first step in investigating the relationship between fingerspelling and print during lexical decision making to explore how activation spreads between these representations. Here, hearing nonnative second-language (L2) learners were examined.

Fingerspelling is the sequential letter-by-letter handshape construction of words in American Sign Language (ASL), with characteristics similar to those of the written alphabet (Padden and Gunsauls 2003; Patrie 1990). That is, one could think of fingerspelling as an orthographic system in ASL. Often fingerspelling is used to nominalize English labels such as places and names (Padden 1998). Fingerspelling resides in an integrated subspace of the native ASL lexicon and enhances the ability to share semantic representations with signs
Connections between Fingerspelling and Print

(Brentari and Eccarius 2010). Furthermore, it is frequently used in everyday ASL (Padden and Gunsauls 2003). Fingerspelling serves as a cross-modal bridge between ASL and English in that it is a manual representation of the English alphabet (see figure 1), while also having some correspondence to ASL signs. The connections to both English print and ASL signs may allow fingerspelling to aid in literacy acquisition in deaf students by connecting fingerspelled words, print words, and ASL signs (i.e., “chaining”; see Chamberlain and Mayberry 2000). Johnson (1994) delineated many of the ways in which fingerspelling connects to literacy acquisition in children. Of particular interest, he notes that deaf children not only acquire fingerspelling early (also see Maestas y Moores 1980; Padden 1990) but also learn associations between the alphabet and fingerspelling very early (also see Williams 1976). These associations have also predicted later literacy performance (Allen 2015; Mayberry, del Giudice, and Lieberman 2011). Additionally, combining fingerspelling, print, and ASL signs in a pedagogical context might not only be advantageous for native deaf signers (Johnson 1994) but also assist L2 acquisition for hearing learners of ASL, given their inability to easily acquire and process fingerspelling (Patrie 1990; Wilcox 1988). As such, it is important to understand the connections between print and fingerspelling processing.

Fingerspelling may prove to be important in literacy acquisition for deaf persons. Some evidence from the literature supports the hypothesis that fingerspelling has positive connections to orthography and reading (Mayberry, del Giudice, and Lieberman 2011; Padden 2006; Padden and Ramsey 2000; Hanson 1982). Although these studies

Figure 1. The top row demonstrates a fingerspelled string, s-a-i-l, for the English word sail, with the corresponding English letters on the bottom row. The fingerspelled stills were extracted from the native signer stimuli as described in the Methods section.
provide a cache of evidence that fingerspelling may facilitate learning to read, Emmorey and Petrich (2011) investigated the association between print and fingerspelling by examining the segmentation of print words and fingerspelled words. The authors examined basic orthographic syllable structure (BOSS; Taft 1979), the parsing of print, and fingerspelling by deaf adults. The BOSS model suggests that orthographic decoding is optimized by a perceptual boundary after nonviolating orthotactic postvocalic consonants (e.g., cand.le for “candle,” such that “dl” is an illegal coda cluster). The authors hypothesized that if fingerspelling activates print representations, then similar segmentation strategies would be implemented. They found that deaf participants parse print and fingerspelling differently. Print was parsed using BOSS segmentation, whereas fingerspelling was parsed using a phonological strategy. The difference in segmentation in print and fingerspelling raises doubt about the activation of print representations from fingerspelling. It may also be the case that the inherent differences in presentation cause differences in segmentation.

Differences in the processing and activation of print and fingerspelling may account for difficulties in fingerspelling comprehension in L2 learners. Several studies have demonstrated that the orthographic system of the first language (L1) influences acquisition and word recognition of L2 orthography. Moreover, Korean-English learners showed more errors in judging homophone foils in English word recognition, whereas Chinese learners made more errors on orthographically similar items than controls (Wang, Koda, and Perfetti 2003). These results suggest that Korean-English learners relied more on phonological information and Chinese-English learners relied more on orthographic information. It was hypothesized that the functional overlap between Korean and English orthographies facilitated a phonological processing strategy, whereas the divergence between English and Chinese orthographies afforded an orthographic processing strategy. Based on this study and others (Koda 1999, 1997, 1989; Chikamatsu 1996), it can be concluded that languages have different affordances for mapping, which subsequently influence L2 acquisition and lexical processing. Some languages, such as English, rely on phoneme-grapheme mappings, while other languages select other units (e.g., syllables or morphemes). More importantly, the differences between L1 and L2 in
their alphabetic mapping strategies can influence L2 word recognition. It is the case that ASL learners would have similar strategies in both L1 (English) and L2 (ASL) because both fingerspelling and print are alphabetic systems. Additionally, priming studies support evidence of cross-linguistic interactions between phonological and orthographic systems. Bilinguals and L2 learners can use both phonological and orthographic information during visual word recognition (Dimitropoulou, Duñabeitia, and Carreiras 2011; Brysbaert 2003). Orthographic and phonological priming studies of monolingual English speakers suggest that overlapping orthographic and/or phonological information facilitates word recognition (Ferrand and Grainger 1994; Lukatela and Turvey 1990). One major difference between English and ASL, unlike English and Chinese, for example, is the sequentiality of letter presentation in ASL fingerspelling, which might significantly influence the learners’ strategy during visual word recognition (Patrie 1990, 1992). Taken together, evidence from cross-linguistic word recognition and priming tasks suggest that it is plausible to assume that hearing learners of ASL would use both phonological and orthographic information while making lexical decisions for both English print and ASL fingerspelling; however, differences in word recognition might emerge due to the temporal dynamics of fingerspelling.

Patrie and colleagues have previously investigated how the temporal dynamics of fingerspelling may affect visual word recognition of fingerspelling by novice and expert hearing signers. Using a rapid serial visual processing task (Patrie and Johnson 2011), it was found that experts were better able to recognize fingerspelled pseudowords than novices (Patrie 1990, 1992). Of particular importance to the present study is that Patrie (1990) tested the ability of novices and experts to recognize both fingerspelling and computer-spelled words (i.e., words that were presented one letter at a time on the computer). Patrie (ibid.) found that novice signers recognized more computer-spelled words than fingerspelled words, but the converse was true for experts. This pattern of findings suggested that experience with the serial presentation of letters (i.e., the temporal dynamics of fingerspelling) directly affects orthographic processing. Given this interaction between fingerspelling and serial letter processing, we are still left to wonder whether print and fingerspelling share similar processing mechanisms.
This study tested the hypothesized ability of a fingerspelling representation to activate print representations and vice versa in hearing signers. In a previous study (Williams, Darcy, and Newman 2015), it was found that the fingerspelling of primes does not facilitate fingerspelled target selection in L2 learners of ASL but that deaf signers did show facilitation in the orthographically related conditions. The priming effects elicited in deaf signers was not surprising as it was within-language priming, where representations are expected to share activation. However, the result for L2 learners was a bit more surprising due to their robust L1 orthographic representations, which were expected to aid in fingerspelling activation. Hearing L2 learners should have been able to bootstrap fully specified orthographic knowledge to aid in fingerspelling retrieval. Thus, it was concluded that the serial nature of fingerspelling must differentially affect lexical retrieval in L2 learners. The current study aimed to explicate the role of temporal dynamics in fingerspelling activation in L2 learners.

A cross-modal priming paradigm was used to determine whether print primes could facilitate the lexical retrieval of a fingerspelled target. If fingerspelling representations activate print representations, then significant facilitation should result when making a lexical decision with regard to print words. Similarly, it was hypothesized that print would activate fingerspelling representations and facilitate lexical decisions about fingerspelling. The study also manipulated phonology to investigate phonological parsing strategies. It was predicted that phonology would influence lexical decision making because phonology is automatically activated with orthography for L1 hearing individuals (Grainger and Ferrand 1994). Based on the previous evidence of a preferred phonological parsing strategy for fingerspelling (for deaf signers), it was hypothesized that, when the prime was fingerspelled, the phonological activation would be greatest and would affect the print target. However, the print prime would activate the phonology less significantly and would not influence the retrieval of the fingerspelled prime. It was hypothesized that the greatest priming effects would occur in conditions where the prime and the target, regardless of whether print or fingerspelling, overlap in orthography, not when they overlap in phonology.
Experiment 1: Fingerspelling and Print Cross-Modal Priming

Methods

Participants. Twenty-four students (three males, two left-handed; age 21.5 ± 1.3 years) from Indiana University participated in Experiment 1. Twenty-three participants were included in the analysis as one student responded immediately at the onset of every trial. These students either have completed or were currently enrolled in Intermediate American Sign Language I or II (third and fourth semester, respectively). All participants gave written informed consent as approved by the Indiana University Institutional Review Board. The participants underwent a battery of tests (see table 1). Each participant’s basic working memory capacity was captured using backward digit span (DS-B). Fingerspelling ability was measured by self-rating on a scale of 1 to 7 for their ability to both understand and produce fingerspelling; the average of both of the scores is presented in FS Rating. Additionally, the VL2 Fingerspelling Reproduction Task (FRT; Morere 2008) was administered, and the participants’ raw score out of 70 is reported. Fingerspelling ability has been shown to correlate significantly with ASL proficiency (Mayberry and Eichen 1991).

Design and Stimuli

The stimuli consisted of 192 print tokens, 96 words, and 96 pseudo-words. The overall mean LogSUBTLwf frequency of the stimuli was 2.92 (Brysbaert and New 2009; Balota et al. 2007). The frequency was not controlled for fingerspelling as there is no official frequency corpus. However, the frequency did not differ for primes or targets in English across conditions ($F(2,138) = 1.31, p = 0.242, \eta^2 = 0.020$). The mean frequency for primes was 2.848 (0.878). Similarly, the mean

| Table 1. Characteristics of the Participants in Experiment 1. |
|-----------------|-------|
| DS-B            | 4.25  (1.03) |
| FS Rating       | 4.35  (1.09) |
| FRT             | 36.8  (11.52) |
frequency for targets was 3.075 (0.645). See the appendix for frequency by condition and relation. The length of word and pseudoword targets ranged from three to five letters, with a mean of 4 ± 0.51. A native deaf signer recorded the fingerspelled stimuli at a careful, but naturalistic, rate of approximately one fingerspelled letter every 625 milliseconds. The fingerspelled words were edited from one frame (before the start of the articulation of the first letter) to another frame (after the end of the last letter).

Target words were divided into three conditions defining the nature of the prime-target relation on related trials: orthographic (e.g., best-beat), phonological (e.g., sign-line), and orthophonological (e.g., pitch-ditch). This division defines the three levels of the Condition factor. Each target word was paired with a related and an unrelated prime, thus defining the two levels of the Relatedness factor in a 3 (Condition) × 2 (Relatedness) factorial design. Unrelated primes did not have significant orthographic (e.g., side-rift) or phonological (e.g. brake-chair) overlap with targets. The letter position at which the orthographic contrast occurred for the primes and targets in the orthographic and the orthophonological pairs also differed. All of the related pairs in the orthophonological condition differed in the first letter (e.g., pitch-ditch, house-mouse, hill-pill), whereas the pairs in the orthographic condition differed in various letter positions (e.g., best-beat, toe-top). The effect of letter position is discussed further later on as it may have unexpected implications for lexical retrieval. The stimuli were counterbalanced among participants so that every word target was tested in both the related and the unrelated conditions, but each target was seen only once by each participant. Pseudoword targets were pronounceable nonwords that were derived from the ARC Nonword Database (Rastle and Coltheart 2002). Primes for the pseudoword targets were real words matched for word length.

Procedure

Participants sat at a 27-inch iMac computer with a 3.2 GHz Intel Core i5 processor. They performed a lexical decision task wherein they were instructed to place their right index finger on the “0” key to respond to pseudoword target words and their left index finger on the “1” key for real target words. Participants were presented with an
instruction screen that accompanied a scripted verbal instruction by the experimenter. After pressing the spacebar to start the trials, a fixation point (+) was presented for 500 milliseconds. Immediately following the fixation point, the prime-target pairs were presented. For the fingerspelling to print (FS-P) prime-target order, the prime token was presented for the duration of the video ($M = 2.23$, $SD = 0.52$ s). It was followed by an interstimulus interval (ISI) of 500 milliseconds. The target item in print was then presented for 250 milliseconds. The participants were instructed to decide whether the target was a real word or not. For the print to fingerspelling (P-FS) condition order, the prime words were presented in print for 250 milliseconds, followed by the same 500-millisecond ISI duration, and then the fingerspelled target was presented. Participants then decided whether the fingerspelled target was a real word or not at any time after the start of the video. They were asked to respond as quickly and as accurately as possible any time after the offset of the target token. Reaction times were recorded from target onset to button response. Accuracy measures were also collected.

Results

Fingerspelling to Print Order. A 2 by 3 analysis of variance (ANOVA) was performed on the reaction times for correct trials in the FS-P condition (see table 2) with the factors Relatedness (related, unrelated) and Condition (orthographic, phonological, orthophonological). This analysis was performed at both the subject ($F_1$) and item ($F_2$) levels. Reactions times that were above or below two standard deviations from the mean were omitted from the analysis (2.7 percent). Both analyses showed a significant effect of Relatedness [$F_1(1,22) = 10.663$, $p < 0.05$, $\eta^2 = 0.326$; $F_2(1,15) = 5.926$, $p < 0.05$, $\eta^2 = 0.624$]. Both analyses indicated no significant effect of condition [$F_1(2,44) = 1.032$, $p = 0.365$, $\eta^2 = 0.045$; $F_2 < 1$]. There was no significant interaction [$F_1$ and $F_2 < 1$]. Planned ad-hoc $t$-tests showed significant inhibition for the orthographic ($−101$ ms) condition [$t_1(22) = 2.614$, $p < 0.05$] and the orthophonological ($−94$ ms) condition [$t_1(22) = 2.087$, $p < 0.05$] at the subject level. There was a trending inhibition for the phonological ($−83$ ms) condition [$t_1(22) = 2.029$, $p = 0.055$]. Significant results were not found at the item level.
An ANOVA on the accuracy data showed a significant effect of Relatedness, in which the related words were more accurate than the unrelated words across conditions at the subject level [$F_1(1,22) = 4.306, p < 0.05, \eta^2 = 0.164; F_2(1,15) = 1.426, p = 0.251, \eta^2 = 0.087$]. There was no effect of condition [$F_1(2,44) = 1.944, p = 0.159, \eta^2 = 0.080; F_2 < 1$]. There was also no significant interaction at either level [$F_1$ and $F_2 < 1$]. Post-hoc $t$-tests did not show significant effects in any condition.

**Print to Fingerspelling Order.** The same 2 by 3 ANOVA was performed on the reaction times for correct trials in the P-FS condition (see table 3) with the factors Relatedness (related, unrelated) and Condition (orthographic, phonological, orthophonological) at both the subject ($F_1$) and item ($F_2$) levels. Reactions times that were above or below two standard deviations from the mean were omitted from the analysis (2.9%). There was a trending effect of Relatedness at the subject level [$F_1(1,22) = 4.180, p = 0.053, \eta^2 = 0.160$] but not at the item level [$F_2 < 1$]. There was a significant effect of Condition at both levels [$F_1(2,44) = 4.034, p < 0.05, \eta^2 = 0.125; F_2(2,30) = 7.762, p < 0.05, \eta^2 = 0.341$]. There was no significant interaction at either level [$F_1$ and $F_2 < 1$]. Planned ad-hoc $t$-tests to differentiate between the effects of orthography and phonology showed that the orthographic (+46 ms) condition was significantly reduced compared to the phonological (+211 ms) condition [$t_1(22) = -2.889, p < 0.01$] but not at the

### Table 2. Reaction Times (RT) and Accuracy for Related and Unrelated Pairs in Each Condition in the Fingerspelling to Print (FS-P) Order at the Subject Level.

<table>
<thead>
<tr>
<th></th>
<th>RT (MS)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Related</td>
<td>Unrelated</td>
</tr>
<tr>
<td>orthographic</td>
<td>879 (57)</td>
<td>778 (54)</td>
</tr>
<tr>
<td>phonological</td>
<td>859 (57)</td>
<td>776 (63)</td>
</tr>
<tr>
<td>orthophonological</td>
<td>839 (57)</td>
<td>745 (62)</td>
</tr>
</tbody>
</table>

The priming effect (PE) is also reported for both reaction times (in milliseconds) and accuracy. Note: Positive numbers indicate faster reaction times and more accurate responses for the related condition relative to the unrelated condition. Standard deviations are given in parentheses.
item level \( t_2 < 1 \). The other conditions are not significantly different from one another.

An ANOVA of the accuracy data did not show a significant difference for Relatedness at the subject level \( [F_1(1,22) = 1.646, p = 0.13, \eta^2 = 0.070] \) but showed a trend toward significance at the item level \( [F_2(1,15) = 4.526, p = 0.05, \eta^2 = 0.232] \). There was no effect of Condition at either level \( [F_1(2,44) = 1.732, p = 0.189, \eta^2 = 0.073; F_2 < 1] \). Also, there was no interaction \( [F_1(2,44) = 1.905, p = 0.161, \eta^2 = 0.080; F_2(2,30) = 1.011, p = 0.375, \eta^2 = 0.063] \). Planned ad-hoc \( t \)-tests showed a trending significance for orthographic conditions, where related words were faster than unrelated words \( [t_1(22) = 2.012, p = 0.057] \), but reached significance at the item level \( [t_2(15) = 3.638, p < 0.01] \). No other conditions were significant.

**Correlational Analysis.** A correlation analysis was performed to explore the relationship between the priming effects observed in each condition at the subject level and working-memory capacity as measured by digit span. In the FS–P condition, learners did not show significant correlations between priming effects and digit span. However, for the P–FS condition a significant correlation between backward digit span and priming effects in the orthographic condition were observed \( (r = 0.500, p = 0.015) \), such that the participants with a greater working-memory capacity demonstrated a larger priming effect. A correlation analysis between fingerspelling ability (i.e., proficiency), as measured

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**Table 3. Reaction Times (RT) and Accuracy for Related and Unrelated Pairs in Each Condition in the Print to Fingerspelling (P-FS) Order at the Subject Level.**

<table>
<thead>
<tr>
<th></th>
<th>RT (MS)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Related</td>
<td>Unrelated</td>
</tr>
<tr>
<td>orthographic</td>
<td>2,775 (107)</td>
<td>2,821 (94)</td>
</tr>
<tr>
<td>phonological</td>
<td>2,907 (160)</td>
<td>3,118 (103)</td>
</tr>
<tr>
<td>orthophonological</td>
<td>2,885 (126)</td>
<td>3,018 (138)</td>
</tr>
</tbody>
</table>

The priming effect (PE) is also reported for both reaction times (in milliseconds) and accuracy. Note: Positive numbers indicate faster reaction times and more accurate responses for the related condition relative to the unrelated condition. Standard deviations are given in parentheses.
by self-rating and the FRT, and priming effects was also performed. There was no significant correlation between priming effects and proficiency.

Discussion. The ASL L2 learners demonstrated significant inhibition during lexical retrieval of the words in the orthographic and orthophonological conditions when the prime was a fingerspelled word and the target was a print word (i.e., FS-P). However, when the prime was a print word and the target was a fingerspelled word (i.e., P-FS), there were null priming effects across all conditions. Differences between subject-level and item-level analysis may be due to reduced power to detect the effect because of the small number of items per condition. Nevertheless, the pattern of inhibition for only fingerspelled primes might be due to the learner having to recode the prime from fingerspelling back into an L1 orthographic representation. Therefore, as the prime is being serially processed, the recoding step significantly slows the processing. Thus, the processing may inhibit lexical retrieval. Inhibition in the phonological condition was reduced relative to the orthographic condition. Reduced inhibition might be due to the fact that learners focus on the orthographic more than the phonological information when decoding fingerspelling, which is similar to what was previously seen in native deaf signers (Williams, Darcy, and Newman 2015). The relatively low fingerspelling ability may have caused null priming effects. However, previous studies have found similar accuracy rates for fingerspelled word recognition in native deaf students (ibid.). Therefore, reduced accuracy may be a result of serial processing of the target and not fingerspelling ability per se. Interestingly, the L2 group also shows increased priming effects in the orthographic condition for print-fingerspelling priming as a function of working-memory capacity. Thus, working memory may influence the speed at which recoding occurs for the serial target. The faster the recoding, the larger the effect of prime activation on lexical retrieval. Also, the absence of a correlation between the participants’ proficiency levels means that the effects are a function of the system and not the participants’ language ability.

The recoding hypothesis may not be the only explanation for inhibition in the fingerspelled prime condition. This pattern of results may
also be due to the temporal structure of the primes and targets more generally. During the print to fingerspelling condition, the reduced priming effects might be attributable to the decay of activation during the decoding of the fingerspelled target. During the fingerspelling to print condition, the temporal sequencing in a serial fashion may also affect lexical retrieval. However, in this case, the serial nature causes the inhibition, which might arise because learners are recoding each letter and combining them in working memory to compute the target while the target appears. The two events happening simultaneously may cause a delay in response, which creates the inhibition (similar to Patrie [1990], who noted that the temporal dynamics of fingerspelling inhibited word recognition). However, it is unclear whether the temporal structure or the recoding mechanism is responsible for the inhibition. In order to test this, hearing nonsigners were tested in Experiment 2 using both a serial presentation of print letters and a holistic, parallel presentation.

Experiment 2: Fingerspelling Simulation in Serial Letter Priming

Experiment 1 left open the question of whether the temporal structure and the serial processing of the prime cause inhibition of lexical retrieval or whether the recoding mechanism from L2 to L1 is the cause. Thus, the current experiment was added in order to resolve this question. In Experiment 2, which used a hearing nonsigner population, the serial nature of the prime was the only variable that could affect lexical retrieval. Since hearing nonsigners cannot recode any information, lexical retrieval should be influenced only by the temporal structure of the print (as with fingerspelling). Therefore, if there are similar results in a similar fingerspelling to print condition for the hearing nonsigners, then it might be the temporal structure of the prime that causes inhibition. On the other hand, if there are null or priming effects for a serial prime, then the recoding hypothesis is further supported.

Methods

Participants. Twenty-four right-handed students (twelve males; age 20.25 ± 1.44 years) from Indiana University participated in Experiment 2. These students were enrolled in an introductory psychology
course and received credit for their participation. The participants preformed the backward digit span ($M = 4.625$, $SD = 1.055$). They all reported to have had no experience with American Sign Language.

*Design and Stimuli.* The same stimuli from Experiment 1 were used in Experiment 2. However, all stimulus presentations were in print; no fingerspelling was included.

*Procedure.* A procedure similar to that in Experiment 1 was used; however, it was modified to serially present print letters (similar to Patrie 1990, 1992). Following the fixation point, the prime-target pairs were presented. To simulate the fingerspelling to print condition from Experiment 1, the prime token was presented letter by letter, with each letter being presented for 625 milliseconds, referred to as serial to whole (S-W). Stimulus presentation time was calculated by taking the average video times for the fingerspelled words in Experiment 1 and dividing them by the mean word length. Each prime was followed by an ISI of 500 milliseconds. The target item in print was then presented for 250 milliseconds. The same lexical decision task as described earlier was used. To simulate the print to fingerspelling condition order, which is called whole to serial (W-S) presentation, the prime words were presented in print for 250 milliseconds, followed by the same 500 millisecond ISI, and the sequentially presented target was presented at the same rate as the whole prime. Each participant saw each target once, but the target was tested in both related and unrelated conditions across subjects. The participants were asked to respond as quickly and as accurately as possible any time after the onset of the target presentation. Reaction times were recorded from target onset to button response. Accuracy measures were also collected.

*Results*

*Serial to Whole Order.* Correct reaction times were analyzed using the same 2 (Relatedness) by 3 (Condition: orthographic, phonological, orthophonological) ANOVA as in Experiment 1 for the words that appeared in the S–W order (see table 4). Reaction times that were above or below two standard deviations from the mean were omitted.
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Table 4. Reaction Times (RT) and Accuracy for Related and Unrelated Pairs in Each Condition in the Serial to Whole (S-W) Order at the Subject Level.

<table>
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<th>RT (MS)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Related</td>
<td>Unrelated</td>
</tr>
<tr>
<td>orthographic</td>
<td>725 (39)</td>
<td>802 (67)</td>
</tr>
<tr>
<td>phonological</td>
<td>726 (48)</td>
<td>725 (38)</td>
</tr>
<tr>
<td>orthophonological</td>
<td>728 (50)</td>
<td>776 (77)</td>
</tr>
</tbody>
</table>

The priming effect (PE) is also reported for both reaction times (in milliseconds) and accuracy. Note: Positive numbers indicate faster reaction times and more accurate responses for the related condition relative to the unrelated condition. Standard deviations are given in parentheses.

from the analysis (2.8 percent). There were no significant effects for reaction times for Relatedness \[F_{1}(1,23) = 3.288, p = 0.083, \eta^2 = 0.125; F_2 < 1\], Condition \[F_{1}(2,46) = 0.990, p = 0.372, \eta^2 = 0.041; F_2 < 1\], or the interaction \[F_{1}(2,46) = 0.668, p = 0.518, \eta^2 = 0.028; F_2 < 1\] at either level. Planned ad-hoc \(t\)-tests did not show a significant priming effect for any condition.

For accuracy rates, there was a significant effect of Relatedness \[F_{1}(1,23) = 9.653, p < 0.05, \eta^2 = 0.296\] and Condition \[F_{1}(2,46) = 4.241, p < 0.05, \eta^2 = 0.156\] at the subject level but not at the item level \[F_2 < 1\]. There was no significant interaction at either level \[F_1\] and \[F_2 < 1\]. Planned ad-hoc \(t\)-tests showed a significant priming effect for the orthophonological condition \[t_{1}(23) = 2.769, p < 0.01\]. No other conditions showed a significant priming effect.

Whole to Serial Order. Reaction times that were above or below two standard deviations from the mean were omitted from the analysis (2.9 percent). Table 5 shows the descriptive statistics for the Whole to Serial condition. The ANOVA revealed a trending effect of Relatedness at the subject level \[F_{1}(1,23) = 3.278, p = 0.083, \eta^2 = 0.125\] and a significant effect at the item level \[F_{2}(1,15) = 10.918, p < 0.01, \eta^2 = 0.421\]. There was no significant effect of Condition \[F_{1}(2,46) = 2.029, p = 0.143, \eta^2 = 0.081; F_2(2,30) = 1.202, p = 0.315, \eta^2 = 0.074\], and the interaction was nonsignificant \[F_{1}(2,46) = 1.887, p = 0.163, \eta^2 = 0.076; F_2 < 1\]. Planned ad-hoc \(t\)-tests also revealed no significant priming
effects for the orthographic or phonological conditions; however, there was significant facilitation for orthophonological conditions (+254 ms) \( t_1(22) = 2.173, p < 0.05; t_2(15) = 4.327, p < 0.01 \).

For accuracy results, there was a significant effect of Relatedness \( F_1(1,23) = 5.927, p < 0.05, \eta^2 = 0.205; F_2 < 1 \) and an interaction \( F_1(2,46) = 4.450, p < 0.05, \eta^2 = 0.162; F_2 < 1 \) at the subject level. There was no significant effect of Condition at either level \( F_1(2,46) = 2.025, p = 0.144, \eta^2 = 0.081; F_2 < 1 \). Planned post-hoc \( t \)-tests revealed that the effect was driven by the orthophonological condition \( t_1(23) = 4.016, p < 0.001; t_2(15) = 4.327, p < 0.001 \), where related words were much more accurate than unrelated words.

**Correlational Analysis.** A similar correlational analysis as reported in Experiment 1 was performed to investigate the role of working memory on the reaction time (RT) priming effects. There were no significant correlations between priming effects and digit span.

**Between-Group Comparison.** A 3 (Condition) by 2 (Relatedness) by 2 (Group) ANOVA was performed on RT data at the subject level to determine whether the groups differed across the order types. For the FS-P and S-W conditions, there was no significant effect of Condition \( F_1(2,90) = 1.240, p = 0.294, \eta^2 = 0.027; F_2(2,30) = 1.221, p = 0.302, \eta^2 = 0.039 \) and no interaction with Group \( F_1, F_2 < 1 \). There was no significant effect for Relatedness \( F_1(1,45) = 2.170, p = 0.148, \eta^2 = \)

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**Table 5. Reaction Times (RT) and Accuracy for Related and Unrelated Pairs in Each Condition in the Whole to Serial (W-S) Order at the Subject Level.**

<table>
<thead>
<tr>
<th></th>
<th>RT (MS)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Related</td>
<td>Unrelated</td>
</tr>
<tr>
<td></td>
<td>PE</td>
<td>PE</td>
</tr>
<tr>
<td>orthographic</td>
<td>2,789 (84)</td>
<td>2,790 (90)</td>
</tr>
<tr>
<td>phonological</td>
<td>2,829 (106)</td>
<td>3,022 (147)</td>
</tr>
<tr>
<td>orthophonological</td>
<td>2,746 (81)</td>
<td>3,000 (146)</td>
</tr>
</tbody>
</table>

The priming effect (PE) is also reported for both reaction times (in milliseconds) and accuracy. Note: Positive numbers indicate faster reaction times and more accurate responses for the related condition relative to the unrelated condition. Standard deviations are given in parentheses.
0.046; $F_2(2,30) = 2.660, p = 0.113, \eta^2 = 0.081\] However, there was a significant Relatedness by Group interaction [$F_{(1,45)} = 13.749, p < 0.001, \eta^2 = 0.234; F_2(2,30) = 4.666, p < 0.05, \eta^2 = 0.135\]. The L2 group had much slower RTs in the related condition than in the unrelated condition compared to the nonsigner group. There was no significant interaction between Condition and Relatedness [$F_1, F_2 < 1\] and the three-way interaction was not significant [$F_1, F_2 < 1\].

For the P-FS and W-S conditions, there was a significant effect of Condition [$F_{(2,90)} = 6.012, p < 0.01, \eta^2 = 0.118; F_2(2,30) = 7.595, p < 0.001, \eta^2 = 0.202\]. The priming effects in the orthographic condition trended toward being faster than the phonological [$t_{(46)} = 1.910, p = 0.062\] and the orthophonological condition [$t_{(46)} = 1.722, p = 0.092\]. There was no interaction between Condition and Group [$F_1 < 1; F_2(2,30) = 1.750, p = 0.182, \eta^2 = 0.055; F_2 < 1\]. There was a significant effect for Relatedness [$F_{(1,45)} = 7.114, p < 0.05, \eta^2 = 0.137; F_2(2,30) = 2.466, p = 0.127, \eta^2 = 0.076\], where related was faster than unrelated across all conditions for both groups. There was no interaction with Group [$F_1, F_2 < 1\]. There was also no significant interaction between Relatedness and Condition [$F_{(2,90)} = 1.920, p = 0.153, \eta^2 = 0.041; F_2 < 1\] or with group [$F_1, F_2 < 1\].

**Discussion**

In Experiment 2, although no statistically significant priming effects were found, all effects trended toward showing faster response times for related pairs than for unrelated pairs; there were no inhibition effects such as that observed in Experiment 1. There were no significant priming effects elicited in any condition in the S-W order. However, there was significant priming in the W-S order for words in the orthophonological condition. There was no significant priming for the phonological conditions across the presentation orders. The absence of phonological priming indicates that participants relied more on the orthographic information than on the phonological information, which might be necessitated by the serial nature of the stimulus presentation. For the W-S presentation order there were also no significant differences between the L2 learners and the nonsigners. Although for the S-W order there was a significant difference between the two groups, the L2 learners had significant inhibition,
whereas the nonsigners showed a small priming effect. Taken together, this suggests that the inhibition seen in Experiment 1 cannot be attributed to the serial nature of the prime as there was no inhibition in the nonnative signers. Moreover, the reduced priming effects in the W-S condition are such that the activation given by the holistic prime does not survive the decoding of the serial target long enough to facilitate its processing. However, there might be enough activation at the beginning of target decoding, as evidenced by increased priming in the orthophonological condition. Activation of the prime is above threshold only at the onset of the target. Experiment 2 thus provides insights into how recoding and timing effect lexical retrieval.

General Discussion

The goal of the current study was to investigate the decoding of fingerspelling in L2 learners of ASL and the connections between fingerspelling and print. The study found that L2 learners had significant inhibition when the prime was a fingerspelled word, but reduced priming effects when the prime was a print word. The inhibition when the prime was fingerspelled was unexpected, given that English orthographic similarity typically results in facilitatory effects. The inhibitory effect for fingerspelling primes may be due to the necessity to recode the fingerspelled word into its English orthographic form and then into its phonological form in order to hold it in verbal working memory. Another important finding is the relationship between working memory capacity and the activation of a recoded target. It was found that learners with higher working-memory capacity showed larger priming effects in the orthographic condition when the target was fingerspelled. We additionally showed that serial, letter-by-letter word presentation, either in fingerspelling or in print, reduces the size of the priming effect. This modulation of priming is likely due to the dissipation of activation before it can facilitate processing of the target. Also, marginal priming in most conditions in Experiment 2, as well as significant priming in the orthophonological condition in the W-S order, illustrates that fingerspelling and print are not necessarily unrelated codes; rather, serially presented information is processed differently from simultaneously presented information regardless of whether it is fingerspelled or printed.
In the first experiment, second-language learners of ASL were tested on their ability to retrieve fingerspelled and printed words based on the type of prime that preceded them. The overarching question was whether learners would exhibit similar priming effects despite modality and language differences across primes and targets. The cross-modal priming methodology is a tool with which the similarities in processing can be tested. The results of Experiment 1 show that printed and fingerspelling representations do indeed interact and suggest that the temporal dynamics of the prime can significantly influence target activation. When the prime was spelled letter by letter (i.e., fingerspelled), the participants showed significant inhibition in retrieving the target. On the other hand, when the prime was presented simultaneously as a holistic print item, there was a trending priming effect \( p = 0.053 \). These results suggest that the serial nature of fingerspelled primes inhibits lexical access due to the recoding strategy employed by the L2 learners. Not only does the activation created by each fingerspelled letter wane too quickly to appropriately prime the target, but also the delayed recoding of the letters may occur too slowly and overlap with the presentation of the target, thereby interfering with the target selection. Inhibition is not present when the prime is presented holistically because the activation of the prime is fast enough to be facilitative. However, statistically significant priming was not observed, likely due to the activation spread by the prime depleting during the fingerspelled target recoding.

Although it seemed that the recoding strategy caused the inhibition in Experiment 1, it was difficult to tease apart the influence of the temporal structure of the prime and the recoding mechanism itself. In Experiment 2, hearing nonsigners participated in a similar study, in which, instead of fingerspelling, they saw the same words as in Experiment 1, but these were presented serially in print. This design allowed for the investigation of the influence of the temporal structure on priming because, arguably, hearing nonsigners would not be recoding any information. Therefore, the effects seen in Experiment 2 delineate the role of temporal dynamics. In contrast to Experiment 1, there were no significant effects across all conditions for the S-W order and only priming in the orthophonological condition in the W-S order. This suggests that, in general, when the prime is presented
serially, the activation energy decays too quickly to aid lexical retrieval. If the holistic prime is presented simultaneously, then the priming occurs, but decoding the target takes too long to aid facilitation.

Despite the fact that a holistic prime does not typically create a robust priming effect for serial targets, activation is known to occur because priming was observed in the orthophonological condition. This is assumed to arise due to the fact that the point at which the vital information is stored is the onset of the target. In this case, the words in the orthographic condition had varying letter positions, at which the primes and the targets differed from one another. On the other hand, the words in the orthophonological condition had only onset differences (e.g., *house*—*mouse*). Since priming occurred in the orthophonological condition only when there was a holistic prime and a serial target, then it can be argued that the point at which prime activation is strongest is approximately at the onset of the target, with the activation waning as a function of time. Thus letter position in serial items influences lexical computation because the activation is still above threshold at the beginning of the target. Letter position modulations of priming have implications for models of lexical retrieval. That is, lexical retrieval is dependent on the sequential time course of activation spreading during lexical search. Previous studies have shown that timing affects the patterns of activation in priming (Spencer and Wiley 2008). The results presented here contribute to the claim that activation has a decaying property. Furthermore, these data support models of competition reduction from unique orthographic information relayed via letter position. System characteristics interact with memory as well. Since fingerspelling primes may be recoded into their English orthographic forms and then into their phonological forms to be held in verbal working memory, the activation of a recoded target may have a significant relationship with working-memory capacity. It was found that learners with greater working-memory capacity showed larger priming effects in the orthographic condition when the target was fingerspelled. Therefore, it can be concluded that both the temporal dynamics and the ability to store the letter by which words are differentiated within the lexicon are important.
In this study, phonology did not show a significant influence on the results. That is, reduced inhibition in Experiment 1 and reduced priming in Experiment 2 for words in the phonological condition suggest that orthographic information is vital to processing fingerspelling and serial letter information. Moreover, the absence of phonological priming (or inhibition) suggests that the learners use a direct orthographic route to the lexical representation. Thus, the phonological information is not needed in sequential fingerspelling or print decoding. Previous findings in the literature that, during the decoding of fingerspelling, a phonological segmentation strategy is preferred to an orthographic one might be unsubstantiated in hearing learners. Although deaf individuals are L2 learners of English print, it might not be useful to assume that fingerspelling and print are stored and activated similarly across the groups. In fact, the divergent parsing strategies may simply arise from group differences in deaf and hearing populations. Variable reading proficiencies and fingerspelling abilities across the groups could influence which parsing strategies are preferred as well. Thus, we restrict our interpretation of these results to suggest that learners might not use phonology during fingerspelling decoding, but we cannot directly make claims about deaf signers.

In general, it seems the activation of the primes that were presented letter by letter wanes too quickly to allow for robust serial priming. Therefore, orthographic priming is highly contingent on parallel processing. However, the timing of the vital information needed for lexical selection can aid in lexical retrieval. We posit that the serial presentation may reduce priming effects, as evident in Experiment 2 and the P-FS condition in Experiment 1. The differences between L2 and nonsigners arise due to the continual recoding in the L2, which causes inhibition and blocks target retrieval. This study was able to explore the similarities and the differences in processing fingerspelling and print and their effect on lexical retrieval. These differences may account for the difficulty in understanding fingerspelling in L2 learners, but not in deaf learners. Moreover, the two codes may be similar enough to use during deaf reading; however, the overt processing of each code is different such that simultaneous processing of print and serial processing of fingerspelling is preferred, which may alter the
activation of lexical items. Processing differences have been consistently attested in previous studies (cf. Emmorey and Petrich 2012).

The lack of priming for sequential primes adds to our understanding of cross-linguistic orthographic influence. As mentioned previously, the similarities in cross-linguistic orthographic systems can actively influence the processing strategies used. This study uncovers another dimension in which orthographies can differ: time. Unlike divergent phonological or orthographic processing (as seen in Korean- and Chinese-English learners), ASL-English learners have difficulty with fingerspelling due to the temporal aspects of fingerspelling. In other words, although the orthographic and phonological information may be used for processing in both languages, difficulties arise due to the extralinguistic temporal dynamics. Difficulty with the temporal dynamics of fingerspelling has been noted previously such that novice L2 learners have more trouble with fingerspelling word recognition than do those with more experience with sign language (Patrie 1990, 1992).

Temporal dynamics may not be the only explanation for reduced priming effects. The stimuli themselves might have reduced the priming effects observed here. Previous studies have shown that the inter-stimulus interval, or the time between the prime and the target, has significant effects on priming. In this study, a 500-millisecond interval was chosen because a shorter interval (e.g., 250 ms) was shown to cause perceptual confusion between the offset of the fingerspelled prime and target in a pilot study. Nevertheless, a longer interval (e.g., 500 ms) has been shown to significantly reduce masked repetition priming effects in comparison to shorter intervals (e.g., 0 to 150 ms; Ferrand 1996), which may be the source of some of the reduced effects seen here. Additionally, word frequency has been shown to influence priming effects (Segui and Grainger 1990; Grainger 1990). The overall log frequencies of the words included in this study were relatively low (2.92). However, word frequencies did not differ for the primes and targets across conditions; thus a reduction in priming effects should not be attributed to word frequency. The processing strategies adopted by the learners may have also reduced the priming effects. The pseudoword targets in this study did not share the same overlap with the primes and word targets. Thus, the learners might
have adopted a shallow processing strategy in which they made lexical decisions based on whether there was overlap or not, rather than a deeper processing strategy that would activate the sublexical features more. Finally, the power to detect priming effects might account for the reduced priming effects seen here. Although the current non-signer sample size is relatively low (compared to other studies), which may affect the power to capture differences in priming, the number of nonsigners did not differ from the L2 learners, who did provide enough power to capture these effects. Thus, we do not believe that power alone can explain these differences. Despite these limitations, the current study does show significant priming and inhibition in hypothesized directions. Therefore, it seems that temporal dynamics can influence lexical retrieval. Furthermore, as one of the first fingerspelling priming studies, the current study provides unique insight in the sequentiality of lexical activation of fingerspelled and printed words.

The present study demonstrates how serial processing, spoken phonology, and letter position can affect the lexical activation of fingerspelling and print. More studies are needed in order to investigate the similarities and differences between fingerspelling and print in order to understand the cognitive and psycholinguistic mechanisms of orthographic processing and literacy acquisition in both deaf readers and L2 learners of sign language.

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References


### Appendix

<table>
<thead>
<tr>
<th>Mean Stimuli Log Frequency</th>
<th>Prime</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>orthography</td>
<td>2.812</td>
<td>2.794</td>
</tr>
<tr>
<td>phonology</td>
<td>2.725</td>
<td>3.279</td>
</tr>
<tr>
<td>orthophonology</td>
<td>3.006</td>
<td>3.151</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2.848</td>
<td>3.075</td>
</tr>
</tbody>
</table>