Journal of Language and Literature, ISSN: 2078-0303, Vol. 6. No. 1. 2015

FINGERSPELLING AND PRINT PROCESSING SIMILARITIES IN DEAF AND HEARING READERS

Joshua Williams[1,2,4], Dr. **Isabelle Darcy**[2,3], Dr. **Sharlene Newman**[1,2]

[1]Psychological and Brain Sciences, [2]Cognitive Science, and [3]Second Language Studies,
[4]Speech and Hearing Sciences, Indiana University **(USA)**
E-mails: willjota@indiana.edu, idarcy@indiana.edu, sdnewman@indiana.edu

DOI: 10.7813/jll.2015/6-1/12

Received: 11.08.2014
Accepted: 12.12.2014

ABSTRACT

There has been great interest in how deaf individuals learn to read, particularly with respect to the question of representations and underlying mechanisms. One (re-)emerging theory has been that deaf readers may recruit fingerspelling representations. This study attempted to delineate the influence of orthography and spoken phonology on visual word recognition of print and fingerspelling. We predicted that deaf students would have increased priming effects for orthographically related print words than phonologically related words in English. Furthermore, we predicted that the same priming effects for print would arise for fingerspelling recognition. Experiment 1 examined print priming in deaf signers, which revealed that deaf readers had similar orthographic priming effects as reported in the hearing literature, but no English phonological priming. In Experiment 2, which examined fingerspelling priming in both deaf and hearing signers, results showed that deaf signers had similar priming effects for both print and fingerspelling that are orthographically similar. For the ASL students, results indicated they may need to directly access their orthographic representations in order to decode fingerspelling. Similarities across Experiments 1 and 2 for deaf students suggested that processing orthography and fingerspelling may use the same underlying mechanisms.

Keywords: literacy acquisition; sign language; fingerspelling

1. INTRODUCTION

Deaf students have been lagging behind their hearing counterparts in literacy skills for decades, with their median reading level upon graduation equivalent to the 4th grade (Traxler, 2000). Debate within the field has failed to converge on the source of the issue, despite much of the field implicating spoken phonological deficits. Models of typical reading place importance on spoken language phonological competence (Liberman & Shankweiler, 1985; Snow, Burns, and Griffin, 1998; Ehri, Nunes, Willows, Schuster, Yaghoub-Zadeh, & Shanahan, 2001). The process of becoming a skilled reader requires mastery of phonological ability and subsequently orthographic ability. Readers have access to both phonological (indirect route) and orthographic (direct route) representations during reading (Harm & Seidenberg, 2004). In beginning stages of reading acquisition, readers are required to map phonological representations to orthography representations (indirect, phonological route). Similarly, less skilled readers (e.g., people with dyslexia) often are characterized by deficits in phonological processing such that weakened phonological representations (Snowling, 2000) and deficits in short-term memory prevent access to semantic representations (Ramus & Szenkovits, 2008). As the reader becomes more skilled, the direct route from orthography to semantics is used for speed and efficiency (Hoover & Gough, 1990). Despite well-specified dual route models, this research has been based on hearing individuals and spoken phonology; it is unknown how deaf readers may process reading and fingerspelling.

Just as the phonological deficit hypothesis accounts for poor reading abilities in atypical reading acquisition in hearing individuals, reduced spoken phonological ability may be the main culprit for diminished reading achievement in deaf individuals (Marschark, Sarchet, Convertino, Borgna, Morrison, & Remelt, 2012). Several studies have attributed deficits in spoken phonological ability due to restricted access to spoken language to low reading achievement in deaf individuals (Stanovich, 2000; Paul, Wang, Trezek, & Luckner, 2009). Nevertheless, there has been much controversy as to the significance of phonological awareness in deaf reading achievement. Miller (1997) has shown that communication mode (i.e., deaf students trained orally) does not predict phonemic awareness, but others have found the opposite (Koo, Crain, LaSasso, & Eden, 2008; Cupples, Ching, Crowe, Day, & Seeto, 2013). However, a meta-analysis suggests that only 11% of the variance in reading ability is contributable to phonological awareness in deaf individuals (Mayberry, del Guidice, & Lieberman, 2011). The authors suggest that signing ability better predicts reading ability. Moreover, some research suggests that phonological abilities in deaf individuals arise from articulatory mechanisms, which only provide partial representations (Hirsh-Pasek & Treiman, 1983). This has led many to investigate alternate mechanisms for literacy acquisition such as the use of sign representations (Treiman & Hirsh-Pasek, 1983) or finer-grained representations of spoken phonology in motoric and/or visual representations (McQuarrie & Parrila, 2009). Some researchers have also argued for the importance of the development of orthographic competence over phonological abilities (Miller 2004).

Despite earlier studies (Locke & Locke, 1971; Hanson, 1982; Hirsh-Pasek, 1987), only recently have researchers revitalized investigations into fingerspelling as an alternative representation; however, only a relatively small number of these studies have investigated the role of fingerspelling in literacy. Previous studies have examined fingerspelling parsing (Emmorey & Petrich, 2011), fingerspelled vocabulary acquisition (Happtonstall-Nykaza & Schick, 2007), and identification, matching, and writing of fingerspelled words (Puente et al., 2006). The current study examined the differential interrelationship between orthography and spoken phonology and print[1] and fingerspelling in a group of deaf students.

American Sign Language (ASL) expresses meaning through handshapes, movement, space, and facial expressions. ASL phonology is composed of several phonological parameters (or features), such has handshape (or configuration), movement, and location (or place of articulation; Brentari, 1998). Well-formed ASL signs contain all of these parameters to represent an arbitrary meaning. Fingerspelling differs from ASL signs insofar as fingerspelling uses handshapes to represent orthographic symbols in sign language. Fingerspelling is the sequential letter-by-letter (or handshape-by-handshape) construction of words with characteristics similar to written symbols (Padden & Gunsauls, 2003). Many have assumed that fingerspelling was an ASL representation of a "foreign" English language (Padden, 1998) designed to nominalize English labels such as places and names. Padden examined the lexical use of fingerspelling in ASL and found that fingerspelling can share semantic meaning alongside native signs, suggesting that in certain cases fingerspelling has become integrated into a subspace of the native ASL lexicon. Fingerspelling straddles a unique cross-modal bridge between ASL and English in that it is a manual representation of the English alphabet (see Figure 1), while also representing signs in ASL. As such, it might be an important window into understanding the connections between print and fingerspelling processing. Namely, fingerspelling provides an alphabetic representation for words, which can be used as an indirect phonological route. In other words, fingerspelling represents the orthography that in turn represents the language-specific spoken phonology. The linking from fingerspelling to spoken phonology provides an indirect route with which less skilled (or beginning) deaf readers may exploit during reading. Phonological representations can also be reinforced in instances where fingerspelling is accompanied by mouthing of the spoken word (Boyes-Braem & Sutton-Spence, 2001). In fact, some promote the process of linking English and fingerspelling as a method to improve literacy among deaf students (Chamberlain & Mayberry, 2000). That is, deaf educators often use a method of "chaining", or the process of "link[ing] words written on the blackboard with both sign and fingerspelling, going back and forth between these lexical representations…" (Chamberlain & Mayberry, 2000). Chaining may provide a crucial bridge between fingerspelling, signs, and print. Subsequently, it seems as though deaf readers may use fingerspelling to aid in reading comprehension.

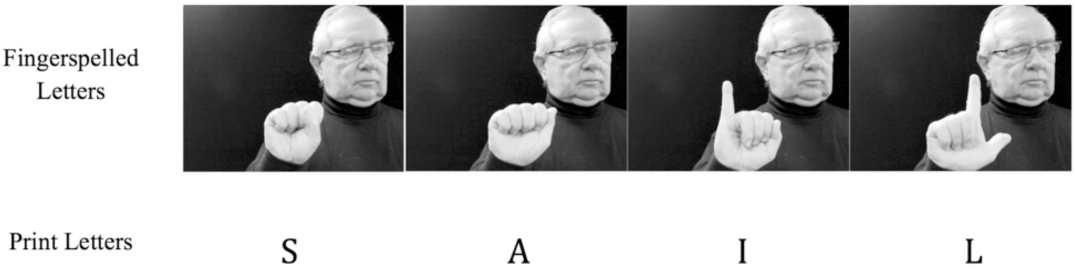

***Fig.1.** The top row demonstrates a fingerspelled string S-A-I-L for the English word sail with the corresponding English letters on the bottom row*

There is some evidence from the literature that supports the hypothesis that fingerspelling may play a pivotal role in learning to read in deaf children. For example, Mayberry et al. (2011) found a correlation between reading and fingerspelling abilities. Additionally, Padden (2006) found that deaf children move from whole-word decoding to decomposition of fingerspelled words to internal handshape structure (i.e., knowledge of C-A-T[2] as CAT to knowledge of C, A, and T as separate units). The process of recognizing that fingerspelled words are composed of smaller units is analogous to whole-word decomposition into English letters by typical readers, which suggests fingerspelling acquisition parallels orthographic competence and phonemic awareness in hearing children. Padden and Ramsey (2000) also found a positive relationship between reading comprehension and the ability to write down an embedded fingerspelled word. Another important finding is that reported by Hanson (1982). She presented deaf adults with fingerspelled words, orthographically regular pseudowords (i.e., prounounceable in English), and orthographically irregular nonwords (i.e., unpronounceable in English). The participants had to write the letter string they saw and make a lexical decision (i.e., if the fingerspelled tokens were real words or not). Her results showed that words had greater letter report accuracy than pseudowords, which were more accurate than nonwords. Importantly, deaf participants' errors never contained orthotactic violations, which may suggest the use of similar strategies for orthographic and fingerspelled stimuli.

Although these studies provide a cache of evidence that fingerspelling may facilitate learning to read for deaf individuals, 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) parsing of print and fingerspelling for deaf adults. The BOSS model suggests that orthographic decoding is optimized by a perceptual boundary after non-violating orthotactic postvocalic consonants (e.g., CAND.LE for "candle", such that "dl" is an illegal coda cluster). They found that, for deaf participants, print is parsed using the BOSS and fingerspelling is parsed using phonological syllable boundaries (e.g., CAN.DLE). They hypothesized that this is inherent to the kinematic mouthing concatenations many signers do with fingerspelling production. They suggested a phonological parsing strategy is needed for fingerspelling. Thus, English phonology may be linked to fingerspelling for deaf individuals just as it is so crucially for hearing in print (Ferrand & Grainger, 1993).

In addition to investigating the decoding processes (i.e., phonological or orthographic) deaf readers use, it is also important to investigate the co-activation of sublexical representations during fingerspelling decoding. Since fingerspelling is implicated in an indirect route, it would suggest that during decoding of fingerspelling, there should be activation of phonological information as well if deaf readers have fully-specified spoken phonological representations for English words. One way to investigate this is through a priming paradigm. For decades, researchers have investigated the role of spoken phonology and orthography on visual word recognition. Word recognition is often faster and more accurate for target words that are preceded by phonologically related word (primes) than orthographic controls (Ferrand & Grainger, 1993; Lukatela & Turvey, 1994). This is thought to be due to robust prelexical phonological activation during reading. By manipulating orthographic and phonological relatedness between primes and targets, the activation and use of a given sublexical representation can be investigated. The investigation of sublexical co-activation in fingerspelling decoding is important to provide theoretical ties between print and fingerspelling decoding in order to develop pedagogical techniques for increasing deaf literacy.

Taken together, previous research suggests that fingerspelling may be involved in the acquisition of literacy for deaf individuals. The reliance on fingerspelling may be due to reduced competence in orthography. Deaf readers may exploit fingerspelling as a bridge between written English and ASL to aid in literacy acquisition. Moreover, deaf signers are attuned to the visuospatial properties of fingerspelling, which may aid in the transition from ASL to English orthography. As they become more proficient readers, deaf readers can hone in on the orthographic regularities and decrease the reliance on fingerspelling. Given the findings of previous researchers, we posit that the mechanisms employed by deaf readers to decode print are similar to those used by hearing individuals. However, English phonology is recoded or represented differently. Beginning (or less-skilled) deaf readers may rely on orthography-to-fingerspelling mappings (i.e., indirect route). This process wanes as a function of skill and ability to automatize ASL-English sign-orthography mappings (i.e., direct route).

The nature of the interactions between the manual instantiation of an orthographic system and lexicon is still unclear. The present study is the first study to investigate the similarities in lexical decision of print and fingerspelling by using a priming paradigm to address whether print decoding is differentially affected by orthographic and/or phonological similarity. Additionally, we extend our investigation to the role of orthography and spoken phonology on fingerspelling decoding. To this end, we aim to draw theoretical similarities between print and fingerspelling decoding in terms of their mappings with orthography and spoken phonology.

These questions were addressed by using a primed lexical decision task. There were three conditions of interest: the prime-target pair had 1) orthographic overlap, 2) English phonological overlap, or 3) both. If deaf individuals are sensitive to orthography and English phonology, similar to native hearing English readers, then it was predicted that deaf readers will show priming (i.e., facilitation in processing) of orthographically and phonologically related words. Alternatively, if their reduced access to the sound-based phonology plays a role in visual word recognition, then priming effects would not be found in prime-target pairs that are phonologically related. However, if they are able to attune to orthographic information, priming effects for orthography may be expected despite reduced English phonology-orthography mappings.

The study was composed of two experiments, one using English print stimuli and one using fingerspelled stimuli. Parallel results were expected for print and fingerspelling due to the similarity of the two representations – fingerspelling is a direct representation of English orthography. That is, words that are either fingerspelled or in print, regardless of phonological information, should be facilitated in lexical retrieval. By extending the paradigm to fingerspelling, we can better characterize the nature of visual language processing as well as learn more about whether fingerspelling representations can be useful in English acquisition for deaf individuals.

EXPERIMENT 1: PRINT PRIMING IN DEAF PARTICIPANTS

2. METHODS

Participants. Thirty-one deaf high school students from the Indiana School for the Deaf participated in this study. Twenty-six (11 male) were included in the analysis, while 5 were excluded due to either clerical error or inability to perform the task. Their ages ranged from 16 to 19 years old with a mean age of 17 ± 1 year. All participants had normal or corrected-to-normal vision. There were three left-handed and 23 right-handed participants. Participants were recruited from a pool of junior- and senior-level students who teachers felt had adequate signing ability to complete the task. That is, students with known language delays in ASL were not recruited. Parental consent was acquired for all students who volunteered for the study per Indiana University Institutional Review Board regulations. On a self-report questionnaire, students reported moderate (40-70 dB HL) to profound (90+ dB HL) hearing loss. Additionally, none of the students indicated significant use of cochlear implants or hearing amplification before or at the time of participation. All of the participants self-reported that ASL was their first and dominate language on a questionnaire administered by the experimenters. Limited access to formal measures of ASL ability prevented the experimenters from gaining a clear picture of the students' ability; however, ASL ability was assessed qualitatively via teacher evaluations, questionnaire self-reporting, and conversations with the experimenters (also the ability to understand signed instructions). The participants self-reported their ability to produce and comprehend both ASL and fingerspelling on a 4-point scale (i.e., "beginner", "intermediate", "advanced", and "native"). The experimenters provided further explanation of these categories for the few students who requested it. Scores ranged from advanced to native for ASL ability and intermediate to native for fingerspelling ability, supporting the students' reports of being fluent in ASL.

Stimuli. The stimulus displays consisted of 192 print tokens, 96 words and 96 pseudowords. The frequency ($\text{LogSUBTL}_{\text{wf}}$; Balota, Yap, Cortese, Hutchison, Kessler, et al., 2007) did not differ for primes or targets in English across conditions [$F(2,138) = 1.31$, $p = 0.242$]. The mean frequency for primes was 2.847 (0.878). Similarly, the mean frequency for targets was 3.074 (0.645). Primes and targets were also matched for word length. The length of word and pseudoword targets ranged from three to five letters ($M = 4$, $SD = 0.51$).

Target words were divided into three conditions that defined the relationship of the prime-target pairs for related trials: orthographic (+O-P; e.g., *best-beat*), phonological (-O+P; e.g., *sign-line*), and ortho-phonological (+O+P; e.g., *pitch-ditch*). Orthographic overlap (+O) was defined as significant overlap of orthographic letters between prime and target pairs. Phonological overlap (+P) was considered as shared segments between the prime and target within the prime-target pair nucleus and significantly more shared phones between primes and targets in the same letter position relative to the –P condition [$t(15) = 6.429$, $p < 0.001$]. Primes on unrelated trials did not have significant orthographic (e.g., *side-rift*) or phonological (e.g. *brake-chair*) overlap with targets. The division based on orthography and phonology overlap 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 Relation factor in a 3 (Condition) X 2 (Relation) factorial design. Words in the orthography condition differ from those in the ortho-phonological condition in the letter position of the difference in the prime-target pair. All of the related pairs in the ortho-phonological condition differed by the first letter (e.g., *house-mouse*), whereas the pairs in the orthographic condition differed in various letter positions (e.g., *best-beat, toe-top*). The pseudowords were generated from the ARC Nonword Database (Rastle & Coltheart, 2002) to be pronounceable non-words. Primes for the pseudoword targets were real words matched for word length. Primes did not have significant orthographic (e.g. *riot-helk*) or phonological (e.g. *loan-vawk*) overlap with pseudoword targets.

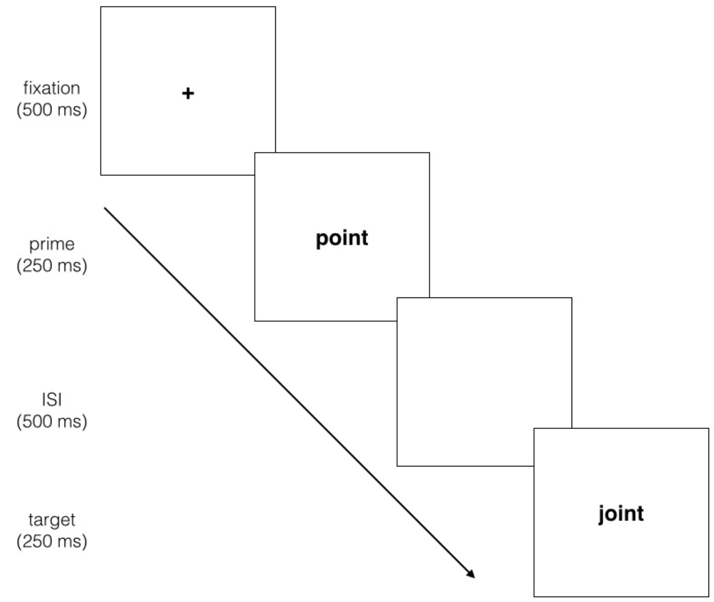

Fig. 2. *Shows a classic priming paradigm, which was used in this experiment.*
A fixation cross precedes the prime word followed by a blank screen and the target,
at which point the lexical decision is made.

Procedure. Participants sat at a MacBook Pro computer with a 2.5 GHz Intel Core i5 processor. The computer was placed so that the keyboard was at a comfortable arm's length from the subject. Participants performed a lexical decision task wherein they were instructed to place their left index finger on the "Y" key to respond to English target words and their right index finger on the "N" key for made-up 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 presentation of the fixation point, the prime-target pairs were presented. The conditions were randomly presented throughout the experiment. The prime token was presented for 250 milliseconds. It was followed by an inter-stimulus interval of 500 milliseconds. The target item (in print) then was presented for 250 milliseconds (see Figure 2 for design). The participants were instructed to decide whether the target was a real word or not; they were asked to respond as quickly and as accurately as possible any time after the offset of the target token. Response times were recorded from target onset to button response. Accuracy measures were also collected.

3. RESULTS

The data were filtered for outliers (i.e., any trial that was two standard deviations from the mean for each subject; see Appendix A1 for descriptive statistics).

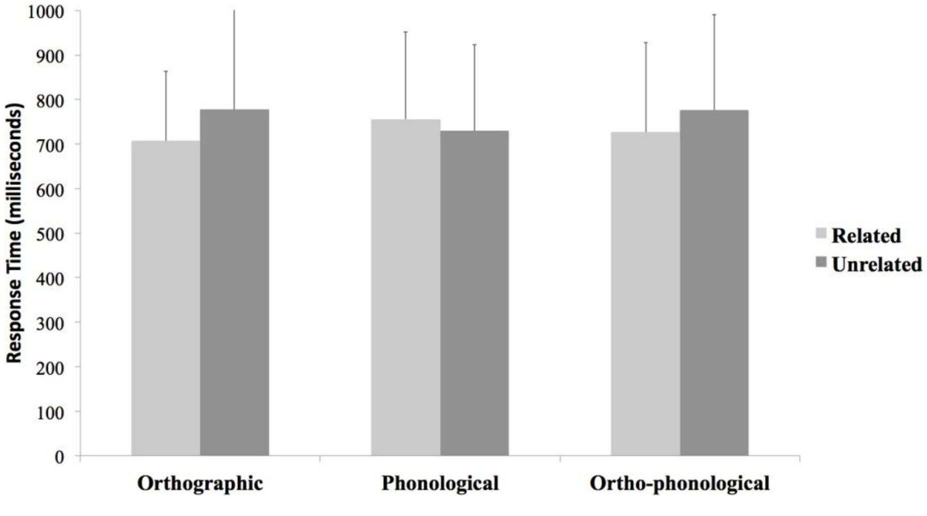

Fig. 3. *Depicts the mean response times (in milliseconds) for each condition*
(orthographic, phonological, and ortho-phonological) for both he related and unrelated pairs.
Errors bars are ± 1 standard deviation.

A 3 (Condition: orthographic, phonological, and ortho-phonological) x 2 (Relation: prime and target) analysis of variance (ANOVA) was run to compare RT differences. There was no significant effect of Condition [$F < 1$] or Relation [$F < 1$]. There was a significant interaction between Condition and Relation [$F(2,52) = 3.804$, $p < 0.05$, $\eta^2 = 0.128$]. Planned post-hoc paired t-tests were performed to understand the priming effects for each condition. The priming effect is the difference between the response times for the unrelated and related pairs. Priming was observed in the orthographic and ortho-phonological conditions, but not in the phonological condition. Related targets were selected more quickly than unrelated targets in the orthographic condition [$t(25) = 2.135$, $p < 0.05$]. Similarly in the ortho-phonological condition, related targets were selected more quickly than unrelated targets [$t(25) = 2.627$, $p < 0.05$]. There was no significant difference in priming effect between orthographic and ortho-phonological conditions [$t(25) = 0.396$, $p > 0.5$]. Reaction times in the phonological condition were significantly slower than in both the orthographic [$t(25) = 2.162$, $p < 0.5$] and ortho-phonological conditions [$t(25) = 2.236$, $p < 0.5$].

A similar 3 by 2 ANOVA was performed on the accuracy data and there were no significant effects. However, the relation factor was trending towards significance [$F(2,25) = 3.804$, $p = 0.055$, $\eta^2 = 0.140$]. Planned post-hoc t-tests were performed to examine whether the trending results were due to one condition. Accuracy differed significantly in the orthographic condition, where responses for related words were more accurate than for unrelated [$t(25) = 2.107$, $p < 0.05$], but not in any other condition.

4. DISCUSSION

In Experiment 1, significant priming effects in both the orthographic (e.g., *best-beat*) and ortho-phonological conditions (e.g., *pitch-ditch*) indicate that the deaf students are attuned to orthographic regularities. It also suggests that if these students have phonological awareness in English, it may not influence (neither facilitate nor impede) their print decoding abilities, as words that rhymed in English did not show priming effects. This differs from the established literature on how hearing readers decode visual words such that phonologically related primes and targets increase word recognition speed (Ferrand & Grainger, 1992, 1994). These differences may suggest that these deaf students are visual readers and do not use spoken English phonology to facilitate reading. We cannot comment on the presence or absence of spoken English phonological awareness, however, as it was not measured.

EXPERIMENT 2: FINGERSPELLING PRIMING IN DEAF AND HEARING INDIVIDUALS

Experiment 1 provides some evidence that these deaf students may attune to orthographic information while reading instead of relying on phonological information. The deaf participants from Experiment 1 completed a second priming study. The stimuli consisted of the same words used in Experiment 1; however the stimuli were counterbalanced to prevent familiarity priming. In Experiment 2, the words were presented as fingerspelled words instead of print words. In order to have a comparison group for these deaf students, hearing ASL students also participated in this study. Both groups provide unique insights into the phonological structure of their lexicons. Deaf participants may have reduced English-based phonological experience, but hearing second language (L2) learners typically have a rich spoken-language phonological system.

5. METHODS

Participants. The deaf student group consisted of the same participants as Experiment 1. In addition, 24 (7 male) students at Indiana University participated in the study. These students were enrolled in or had taken the Intermediate I and II courses of American Sign Language (3rd and 4th semester, respectively). Their ages ranged from 18 to 27 years old with a mean age of 21 ± 1.7 years. All participants had normal or corrected-to-normal vision. There were two left-handed and 22 right-handed participants. All participants reported their first language as English. No participant self-reported a hearing loss on the background questionnaire. They self-reported as being intermediate to advanced on fingerspelling ability, similar to the fingerspelling ratings given by the deaf students.

Stimuli. The stimuli consisted of fingerspelled videos of the same print in Experiment 1. Prime-target pairs were split into conditions based on the same three relationships described in Experiment 1. A 3 (Condition: orthographic, phonological, and ortho-phonological) x 2 (Type: prime and target) ANOVA was run to confirm that the lengths of the videos were the same across primes and targets in all conditions. There was no significant difference for videos across conditions [$F(2, 30) = 0.738$, $p > 0.05$, $\eta^2 = 0.487$]. Moreover, primes and targets were not different across conditions [$F(2, 30) = 0.335$, $p > 0.1$, $\eta^2 = 0.487$]. The lengths of videos were matched within condition with an overall mean length of 2230 (52) milliseconds. The tokens were slowly and carefully fingerspelled in order to ensure comprehension. The signer did not include mouthings with any of the fingerspelled strings. The total stimuli were split across two experimental lists in order to counterbalance across participants so that no participant saw the same prime or target more than once. More importantly, counterbalancing prevented the deaf participants from Experiment 1 from seeing the same words also fingerspelled in this experiment.

6. RESULTS

The data were filtered for outliers (i.e., any trial that was two standard deviations from the mean for each subject; see Appendix A2 for descriptive statistics).

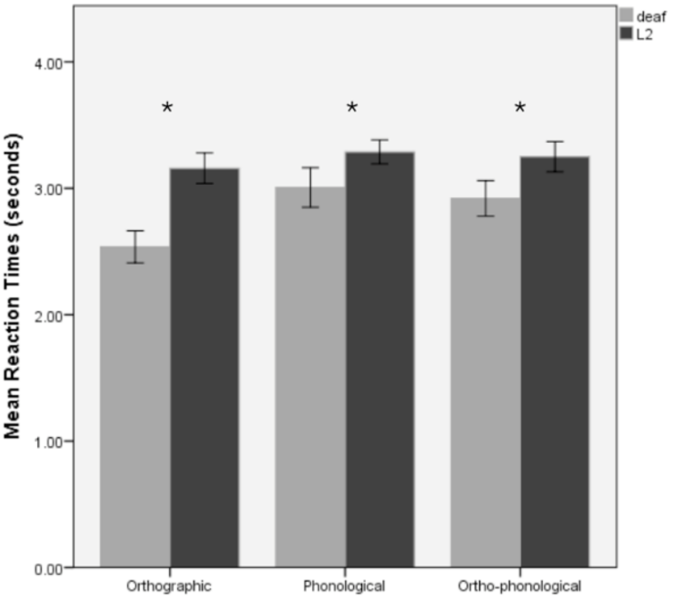

Fig.4. *Since there were no significant interactions with relation, the graph depicts lexical decision response times for words in Experiment 2 across both groups. The responses by the deaf participants are in grey and the hearing L2 learners in black.*

Hearing ASL Students

No priming effects were elicited.

Deaf Students

A similar 3 (Condition: orthographic, phonological, and ortho-phonological) by 2 (Relation: prime and target) ANOVA suggests that the conditions were significantly different [$F(2, 50) = 18.063$, $p < 0.001$, $\eta^2 = 0.419$], but no other significant effects were found. A planned post-hoc paired t-test was performed to characterize the priming effects within condition. Priming effects were only observed in the orthographic condition, with related targets being responded to more quickly than unrelated targets [$t(25) = 2.165$, $p < 0.05$]. Moreover, RTs on the orthographic condition are significantly faster than the phonological [$t(25) = 4.203$, $p < 0.001$] and ortho-phonological condition [$t(25) = 3.775$, $p = 0.001$], but phonological and ortho-phonological were not significantly different [$t < 1$].

Differences in accuracy were not significant.

7. COMPARISON BETWEEN DEAF AND HEARING SIGNERS

A between-subjects ANOVA was computed to determine whether there were differences between the two groups. Condition and Relation were the within-subject factors and Group (L2 vs. deaf) as a between-subjects factor. The ANOVA revealed that there was a significant Group by Condition interaction such that deaf signers were faster than hearing in responding in all conditions [$F(2, 96) = 5.369$, $p < 0.01$, $\eta^2 = 0.101$]. There were no significant interactions with relation (see Figure 4).

The same ANOVA was performed to examine accuracy differences. There was a significant effect of Condition by Group [$F(2, 96) = 3.464$, $p < 0.05$, $\eta^2 = 0.066$]. Thus, the deaf participants were more accurate than the hearing learners across conditions.

8. DISCUSSION

In Experiment 2, we found a priming effect for the orthographic condition for the deaf students with fingerspelled stimuli, just as in Experiment 1 with print stimuli. These priming effects indicate that deaf students in this study use handshape information to retrieve words in the lexicon. Therefore, regardless of visual representation format, processing is similar for fingerspelling and print for deaf students. It is interesting to note that fingerspelled words that had no orthographic overlap (i.e., phonological condition) did not show priming effects. This means that these deaf students may not need a sound-based phonological feature to access these words in their lexicon[3], but rather adhere to the visual statistics of a target modality. Unlike in Experiment 1, the ortho-phonological condition also did not show any significant priming. The hearing L2 learners did not show any priming effects for any condition. At present, we cannot make strong claims about the mechanisms underlying the lack of facilitation, but several possible explanations exist. One possible explanation is that the hearing students' reduced fingerspelling ability may prevent priming effects. Another possible explanation is that priming effects are diminished due to a possible need for them to recode fingerspelling into L1 orthography first. This recoding requires time and resources, which may wash out priming effects.

9. GENERAL DISCUSSION

The goal of the current study was to determine whether deaf readers attune to orthographic and phonological information during visual word recognition and, if so, does fingerspelling interact with orthographic and phonological information similarly.

The results suggest that print and handshape are processed in a similar manner by the deaf signers. The processing similarities between the two provide insight into possible mechanisms for visual word recognition in deaf readers.

Visual Word Recognition for Deaf Signers

In Experiment 1, orthographic and ortho-phonological priming suggests these deaf readers may have readied access to orthographic information. The absence of significant difference between the priming effects across conditions tends to suggest that participants conflate orthographic and ortho-phonological overlap into one orthographic-only condition. Thus, orthography might be the reigning representation for deaf readers with little reliance on English phonology. This follows from the ecological influence on the deaf students' linguistic system such that they are more attuned to visual statistics. In Experiment 2, when the same words were presented as fingerspelled tokens, priming effects occurred in the same orthographic domain. This is not direct evidence, and as such should be interpreted cautiously, but one possibility is that the finding of similar activation across different presentation types is an indication that similar processes are involved; it may be the case that deaf students process fingerspelling like orthography, or vice versa. These data thus provide important information about language processing more generally.

The results presented here seem to support the hypothesis that some deaf signers might not use sound-based phonological information in either fingerspelling or print, but rather may rely on handshape or orthographic information. The present data cannot help untangle whether this effect is driven by their orthographic or sign ability. It is possible, however, that these representations are void of English phonological information despite activation of orthography, as suggested by Allen et al. (2009). Furthermore, words with similar handshape information provide faster lexical access compared to words with underlying sound-based English phonological overlap. This seems to suggest that the deaf students in this study used visual information (handshape or print) in order to access words in their lexicon. However, in the absence of measures of phonological awareness in both English and ASL, it is hard to make a definitive conclusion as to the role of sound-based English phonology and sign-based ASL phonology in visual word recognition for individual students.

It is not clear why words in the fingerspelled ortho-phonological condition of experiment 2, which maximally overlap in orthographic information (e.g., *pitch-ditch*), did not elicit a priming effect for the deaf students as it did in the parallel ortho-phonological condition with print stimuli. Failure to elicit priming effects may be due to the position of the letter that signals the contrast between the prime and target within a given pair, and to the specific presentation format of fingerspelled vs. print stimuli. The location of the different letter in the prime-target pairs in the orthographic condition varied (e.g., *king-kind, best-beat*). For the ortho-phonological condition the location of the differing letter was always at the onset (e.g., *pitch-ditch, house-mouse*). This maximal overlap appears to interfere with priming for fingerspelled stimuli but not English orthographic stimuli. One difference between the two presentation formats is the serial nature of fingerspelling; participants get one letter at a time and therefore must hold each letter in working memory until the last letter is presented and then combine them to form the word. In terms of lexical access, the serial presentation of each letter of the word may be expected to result in serial lexical activation such that in the case of *pitch*, all words that begin with *p* are activated, then words that begin with *pi* and so forth. In the print condition, lexical activation is quite different in that the letters are processed in parallel (Grainger & Ziegler, 2011; Grainger & van Heuven, 2003). The sequential decoding may lead the participant down a garden path resulting in no priming. These differences may explain why priming arises for the words in the ortho-phonological condition with print stimuli, but not with fingerspelled stimuli for deaf participants.

L2 Differences in Fingerspelling Processing

Hearing ASL L2 learners did not demonstrate any priming effects in fingerspelling word recognition. The lack of priming may be due to various factors; among them are differences in fingerspelling proficiency and recoding strategies. Although the L2 learners rated themselves similarly to the deaf students on fingerspelling ability, the accuracy data show differences across the groups. Just as lower L2 proficiency impacts L2 visual word recognition in learners (Koda, 1996), these learners' inability to quickly process fingerspelling may interfere with lexical priming.

Another possible explanation for the lack of priming observed for the hearing L2 group is related to how fingerspelled words are processed by the hearing group. These hearing L2 learners have a rich and robust L1 orthographic system. It is most likely the case that hearing bimodal bilinguals recode their L2 fingerspelling into L1 orthographic representations. Again, because of the serial nature of fingerspelling the participant must hold each letter in memory until a word can be formed. It is likely that for these hearing L2 learners that this information is being held in verbal working memory in a phonological representation. Therefore the fingerspelled letters may be first converted to the analogous letter and then to a phoneme. Converting fingerspelling into orthographic and then phonological form may significantly slow activation of L1 phonological word representations such that any activation that is within the lexical system has dissipated, preventing the observation of priming effects for the hearing L2 learners.

The finding of priming for the deaf students for the orthographic condition but a lack of priming for the hearing L2 learners suggests that the deaf students are not processing the fingerspelled stimuli in the same way as the hearing participants. Deaf individuals are not likely to convert fingerspelling into a phonological form the way the hearing participants are; instead, they may keep them in a visuospatial format, either a fingerspelled one or an English orthographic one, and hold each serially presented letter in their visuospatial working memory. In either case, fewer transformation steps are likely to occur for the deaf students and may explain their faster response time as well as the priming effect observed. For the L2 learners, it may be the case that over time, priming effects may arise due to long-term strengthening of the connections between fingerspelling and orthographic representations. However, further studies are necessary to fully characterize the processing taking place for both the deaf and the hearing L2 groups.

10. CONCLUSION

This study provides evidence that spoken phonology does not facilitate print recognition for deaf signers. Instead, deaf signers seem to rely on visual statistics, such as orthography, to recognize print words. Moreover, the continued lack of English phonological priming effects for fingerspelling, even for hearing participants with rich sound representations, may be evidence against the need for phonological information for fingerspelling recognition as hypothesized by Emmorey and Petrich (2011). Spoken phonology may aid in fingerspelling recognition for speech-proficient deaf signers as well as hearing signers for longer, low frequency words (like those used in Emmorey and Petrich, 2011), which often need to be sounded out; however, English phonology did not prime the activation of fingerspelling representations for either group in the current study. Significantly faster response times for fingerspelled words overlapping in orthographic information than words overlapping in spoken phonology for deaf signers suggest that orthographic, visual representations are vital to fingerspelling recognition.

To return to the broader implications related to deaf reading, our findings provide evidence that fingerspelled representations are analogous to visual orthographic information. It may be the case that some deaf signers, when reading in their L2, require more overt strategies and processing components to access lexical information within the lexicon. Overt strategies for creating and accessing representations might be modulated by ASL fluency and orthographic competency. The quality of these representations might determine the path used for lexical retrieval, either through ASL signs or fingerspelled representations. These results have important implications on previous strategies that use fingerspelling during the acquisition of English reading. More specifically, this urges deaf educators use the aforementioned method of "chaining", or the process of "link[ing] words written on the blackboard with both sign and fingerspelling, going back and forth between these lexical representations…" (Chamberlain & Mayberry, 2000). Chaining may provide the key educational tool to support orthographic processing and linguistic bootstrapping in literacy acquistion.

As one of the first priming studies of fingerspelling, the current study calls for a more complete investigation of the lexical interactions between fingerspelling, orthography and English phonology. More studies are needed in order to completely tease apart these connections, to better understand the relationship between representations, and model processing and memory constraints in orthographic processing in multi-modal, multi-linguistic lexicons. Nevertheless, the present work establishes that fingerspelling and print may be processed similarly for deaf readers. Add to the growing evidence that deaf readers may be able to use fingerspelling to help with reading (e.g., Happtonstall-Nykaza & Schick, 2007; Chamberlain & Maryberry, 2000). This study also continues to revitalize discussions on how fingerspelling may help deaf readers improve reading and the role of English phonology in reading.

Endnotes:

[1] *In this study, the term "print" refers to the mode of presentation of written words in English. This is not to be mistaken with "orthography". As orthographic similarity (i.e., words that are spelled similarly) is used for both words that are presented in fingerspelling and in print, it is important to make a clear distinction between "print" and "orthography".*

[2] *According to linguistic convention, fingerspelled words are represented in small, capitalized letters with hyphens between the letters (e.g., C-A-T). Additional, lexical signs are represented in small, capitalized letters (e.g., CAT).*

[3] *If they do a phonological representation, however, it might suggest that the reduced form may slow retrieval and ultimately block the predicted priming effects. However, this is unknown from the current study.*

REFERENCES

1. Allen, T. E., Clark, M. D., del Giudice, A., Koo, D., Lieberman, A., Mayberry, R., & Miller, P. (2009). Phonology and reading: A response to Wang, Trezek, Luckner, and Paul. *American Annals of the Deaf*, *154*(4), 338-345.
2. Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., Neely, J. H., Nelson, D. L., Simpson, G. B., & Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods*, 39, 445-459.
3. Boyes-Braem, P., Sutton-Spence, R., & Leiden, R. (Eds.). (2001). *The hands are the head of the mouth: The mouth as articulator in sign languages*. Signum.
4. Brentari, D. (1998). *A prosodic model of sign language phonology*. Cambridge, MA: MIT Press.
5. Chamberlain, C., & Mayberry, R. I. (2000). Theorizing about the relation between American Sign Language and reading. *Language acquisition by eye*, 221-259.
6. Cupples, L., Ching, T. Y., Crowe, K., Day, J., & Seeto, M. (2014). Predictors of early reading skill in 5-year-old children with hearing loss who use spoken language. *Reading Research Quarterly*, *49*(1), 85-104.
7. Ehri, L.C., Nunes, S. R., Willows, D. M., Schuster, B. V., Yaghoub-Zadeh, Z., & Shanahan, T. (2001). Phonemic awareness instruction helps children learn to read: Evidence from the National Reading Panel's meta-analysis. *Reading Research Quarterly*, *36*(3), 250-287.
8. Emmorey, K. and J. A. Petrich (2011). "Processing orthographic structure: Associations between print and fingerspelling." *Journal of Deaf Studies and Deaf Education*, 17(2), 194-204. doi: 10.1093/deafed/enr051
9. Ferrand, L., & Grainger, J. (1993). The time course of orthographic and phonological code activation in the early phases of visual word recognition. *Bulletin of the Psychonomic Society*, *31*(2), 119-122.
10. Grainger, J., & Ziegler, J. C. (2011). A dual-route approach to orthographic processing. *Frontiers in Psychology*, *2*.
11. Grainger, J., & Van Heuven, W. (2003). Modeling letter position coding in printed word perception. *The Mental Lexicon*, 1-24.
12. Hanson, V. L. (1982). Use of orthographic structure by deaf adults: Recognition of fingerspelled words. *Applied Psycholinguistics*, *3*(04), 343-356.
13. Haptonstall-Nykaza, T. S., & Schick, B. (2007). The transition from fingerspelling to English print: Facilitating English decoding. *Journal of Deaf Studies and Deaf Education, 12*(2), 172-183.
14. Harm, M. W., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: cooperative division of labor between visual and phonological processes. *Psychological Review*, *111*(3), 662.
15. Hirsh-Pasek, K. (1987). "The metalinguistics of fingerspelling: An alternate way to increase reading vocabulary in congenitally deaf readers." *Reading Research Quarterly,* 455-474.
16. Hirsh-Pasek, K., & Treiman, R. (1983). Recoding in silent reading: Can the deaf child translate print into a more manageable form?. *The Volta Review*.
17. Hoover, W. A., & Gough, P. B. (1990). The simple view of reading. *Reading and writing*, *2*(2), 127-160.
18. Koda, K. (1996). L2 word recognition research: A critical review. *The Modern Language Journal*, *80*(4), 450-460.

19. Koo, D., Crain, K., LaSasso, C., & Eden, G. F. (2008). Phonological Awareness and Short-Term Memory in Hearing and Deaf Individuals of Different Communication Backgrounds. *Annals of the New York Academy of Sciences*, *1145*(1), 83-99.
20. Liberman, I. Y., & Shankweiler, D. (1985). Phonology and the problems of learning to read and write. *Remedial and Special Education*, *6*(6), 8-17.
21. Locke, J. L., & Locke, V. L. (1971). Deaf children's phonetic, visual, and dactylic coding in a grapheme recall task. *Journal of Experimental Psychology*, *89*(1), 142.
22. Lukatela, G., & Turvey, M. T. (1994). Visual lexical access is initially phonological: 2. Evidence from phonological priming by homophones and pseudohomophones. *Journal of Experimental Psychology: General*, *123*(4), 331.
23. Marschark, M., Sarchet, T., Convertino, C. M., Borgna, G., Morrison, C., & Remelt, S. (2012). Print exposure, reading habits, and reading achievement among deaf and hearing college students. *Journal of Deaf Studies and Deaf Education*, *17*(1), 61-74.
24. Mayberry, R. I., del Giudice, A. A., & Lieberman, A. M. (2011). Reading achievement in relation to phonological coding and awareness in deaf readers: A meta-analysis. *Journal of Deaf Studies and Deaf Education*, *16*(2), 164-188.
25. McQuarrie, L., & Parrila, R. (2009). Phonological representations in deaf children: rethinking the “functional equivalence” hypothesis. *Journal of Deaf Studies and Deaf Education*, *14*(2), 137-154.
26. Miller, P. (2004). Processing of written word and nonword visual information by individuals with prelingual deafness. *Journal of Speech, Language, and Hearing Research*, *47*(5), 990-1000.
27. Miller, P. (1997). The effect of communication mode on the development of phonemic awareness in prelingually deaf students. *Journal of Speech, Language and Hearing Research*, *40*(5), 1151.
28. Padden, C. A. (1998). The ASL lexicon. Sign Language and Linguistics, 1, 39–60. doi:http://dx.doi.org/10.1075/sll.1.1.04pad
29. Padden, C. A. (2006). Learning to fingerspell twice: Young signing children’s acquisition of fingerspelling. In B. Schick, M. Marschark, & P. E. Spencer (Eds.), *Advances in the Sign Language Development of deaf Children* (pp. 189–201). New York: Oxford University Press. doi: 10.1007/978-1-4614-5269-0
30. Padden, C. A. and D. C. Gunsauls (2003). "How the alphabet came to be used in a sign language." *Sign Language Studies,* 4(1), 10-33.
31. Padden, C.A. and Ramsey, C. (2000). American Sign Language and reading ability in deaf children. In C. Chamberlain, J.Morford, and R. Mayberry (Eds.), *Language acquisition by the eye*. (pp. 165-189). Mahway, NJ: Lawrence Erlbaum & Associates.
32. Puente, A., Alvarado, J. M., & Herrera, V. (2006). Fingerspelling and sign language as alternative codes for reading and writing words for Chilean deaf signers. *American Annals of the Deaf*, *151*(3), 299-310.
33. Ramus, F., & Szenkovits, G. (2008). What phonological deficit?. *The Quarterly Journal of Experimental Psychology*, *61*(1), 129-141.
34. Rastle, K., Harrington, J., & Coltheart, M. (2002). 358,534 nonwords: The ARC Nonword Database. *Quarterly Journal of Experimental Psychology*, 55A, 1339-1362.
35. Snow, C. E., Burns, M. S., & Griffin, P. (Eds.). (1998). *Preventing reading difficulties in young children*. National Academies Press.
36. Snowling, M. J. (2000). *Dyslexia* . Blackwell Publishing.
37. Stanovich, K. E. (2000). *Progress in understanding reading: Scientific foundations and new frontiers*. Guilford Press.
38. Taft, M. (1979). Lexical access-via an orthographic code: The basic orthographic syllabic structure (BOSS). *Journal of Verbal Learning and Verbal Behavior*, *18*(1), 21-39.
39. Traxler, C. B. (2000). The Stanford Achievement Test: National norming and performance standards for deaf and hard-of-hearing students. *Journal of Deaf Studies and Deaf Education, 5*, 337-348.
40. Treiman, R., & Hirsh-Pasek, K. (1983). Silent reading: Insights from second-generation deaf readers. *Cognitive Psychology*, *15*(1), 39-65.

APPENDIX

Table 1. Descriptive Statistics for Print Priming for Deaf Students

	Related			Unrelated			Priming Effect
	RT		Accuracy	RT		Accuracy	
Orthographic	707	(156)	93.2%	778	(258)	86.5%	+71*
Phonological	756	(196)	92.3%	730	(193)	88.4%	-26
Ortho-phonological	727	(201)	93.7%	777	(213)	90.4%	+50*

Table 1 outlines the response time (in milliseconds) and accuracy data for each condition in the print priming paradigm for deaf students. RTs are measured from the onset of the stimulus. The priming effect is calculate by taking $RT_{Unrelated} - RT_{Related}$, where positive numbers show priming and negative numbers show inhibition. *Difference between response time is significant.

Table 2. Descriptive Statistics for Fingerspelling

	Deaf Students				
	Related		Unrelated		Priming Effect
	RT	Accuracy	RT	Accuracy	
Orthographic	2.417 (0.680)	82.3%	2.583 (0.605)	82.4%	+166*
Phonological	2.863 (0.822)	80.4%	3.043 (0.884)	77.9%	+180
Ortho-phonological	2.874 (0.820)	85.9%	2.881 (0.689)	78.9%	+7
	Hearing L2 Students				
	Related		Unrelated		Priming Effect
	RT	Accuracy	RT	Accuracy	
Orthographic	3.129 (0.641)	64.9%	3.190 (0.676)	65.9%	+61
Phonological	3.224 (0.560)	68.3%	3.352 (0.588)	70.9%	+128
Ortho-phonological	3.189 (0.713)	78.7%	3.309 (0.642)	74.9%	+120

Table 2 outlines the response time (in seconds) and accuracy data for each condition in the print priming paradigm for deaf students. RTs are measured from the onset of the stimulus. The priming effect is calculate by taking $RT_{Unrelated} - RT_{Related}$, where positive numbers show priming and negative numbers show inhibition. L2 = second language. *Difference between response time is significant.