

# Processing Orthographic Structure: Associations Between Print and Fingerspelling

Karen Emmorey<sup>\*,1</sup>, Jennifer A. F. Petrich<sup>2</sup>

<sup>1</sup>San Diego State University

<sup>2</sup>San Diego State University Research Foundation

Received August 29, 2011; revisions received November 3, 2011; accepted November 13, 2011

Two lexical decision experiments are reported that investigate whether the same segmentation strategies are used for reading printed English words and fingerspelled words (in American Sign Language). Experiment 1 revealed that both deaf and hearing readers performed better when written words were segmented with respect to an orthographically defined syllable (the Basic Orthographic Syllable Structure [BOSS]) than with a phonologically defined syllable. Correlation analyses revealed that better deaf readers were more sensitive to orthographic syllable representations, whereas segmentation strategy did not differentiate the better hearing readers. In contrast to Experiment 1, Experiment 2 revealed better performance by deaf participants when fingerspelled words were segmented at the phonological syllable boundary. We suggest that English mouthings that often accompany fingerspelled words promote a phonological parsing preference for fingerspelled words. In addition, fingerspelling ability was significantly correlated with reading comprehension and vocabulary skills. This pattern of results indicates that the association between fingerspelling and print for adult deaf readers is not based on shared segmentation strategies. Rather, we suggest that both good readers and good fingerspellers have established strong representations of English and that fingerspelling may aid in the development and maintenance of English vocabulary.

Although orthography is traditionally defined as a method of representing the sounds of a language by written symbols, the sounds of a language can also be represented indirectly by fingerspelling: nonwritten symbols in which each letter of an alphabetic script is represented by a distinct hand configuration. For deaf signers in North America, fingerspelling is based on English orthography and

forms an integral component of the American Sign Language (ASL) lexicon (Brentari & Padden, 2001; Padden, 1998). Fingerspelled words are quite frequent in ASL narratives—up to 30% of total vocabulary (Padden & Gunsauls, 2003). In addition, deaf children who are immersed in signing environments (deaf families or bilingual classrooms) are exposed to fingerspelling as a method of English literacy instruction by both parents and teachers (Padden, 2006). Thus, ASL signers experience English orthography in two forms: printed words and fingerspelled words. The primary aim of the study reported here was to investigate how deaf adult readers interpret these different orthographic representations. Specifically, we examined whether orthographic strategies for parsing printed words transfer to fingerspelled words and vice versa.

We focus on what Haptonstall-Nykaza and Schick (2007) term “neutral fingerspelling,” in contrast to “lexicalized fingerspelling” in which fingerspelled words have been borrowed into the ASL lexicon (Battison, 1978; Brentari & Padden, 2001). Reflecting this division, Padden (2006) argued that deaf children “learn fingerspelling twice.” Initially, they acquire lexicalized fingerspelling without instruction and without an awareness that individual handshapes map to English alphabetic letters. When deaf children begin to learn to read, however, they also begin to learn neutral fingerspelling, which functions to represent an English printed word. Some fingerspelled forms that were acquired holistically are then analyzed as sequences of handshape segments. This process of “re-learning” is not unlike how hearing children learn to reanalyze

\*Correspondence should be sent to Karen Emmorey, Laboratory for Language and Cognitive Neuroscience, San Diego State University, 6495 Alvarado Road, Suite 200, San Diego, CA 92120, USA (e-mail: kemmorey@mail.sdsu.edu).

holistically acquired spoken words into sequences of phonemes when they learn to read (Haptonstall-Nykaza & Schick, 2007; Jusczyk, 1997).

There is growing evidence that fingerspelling may serve a critical link between word learning and reading for deaf children and adults (Chamberlain & Mayberry, 2000; Haptonstall-Nykaza & Schick, 2007; Hile, 2009; Hirsh-Pasek, 1987; Locke & Locke, 1971; Padden & Ramsey, 1998, 2000). Deaf readers use fingerspelling in a variety of ways as an aid to decode printed text. For example, Hirsh-Pasek (1987) found that deaf readers identified more sight words when they were encouraged to recode them into fingerspelling. More recently, Haptonstall-Nykaza and Schick (2007) showed that a training method that incorporated fingerspelling increased deaf children's ability to recognize and write printed English words and argued that fingerspelling can serve as a visual phonological bridge to facilitate the decoding of English print. Supporting this hypothesis, Padden and Ramsey (1998, 2000) found a correlation between fingerspelling comprehension and reading comprehension for a large group of elementary and middle-school deaf children (see also Hile, 2009). In addition, Padden and Ramsey (1998, 2000) systematically observed the use of fingerspelling in a number of classrooms and found that teachers frequently used a pedagogical technique that they refer to as "chaining," in which teachers form an association between a printed and fingerspelled word. Such chaining structures provide a tangible link that mediates between English print and ASL fingerspelling. In the experiment presented here, we investigated whether there might be structural correspondences and parsing strategies that are common to fingerspelling and print for adult readers. Though much attention has been paid to deaf readers' phonological processing (e.g., Conrad, 1979; Perfetti & Sandak, 2000), little attention has been paid to their orthographic processing or how orthographic processing of print may be related to processing of fingerspelling.

Many studies have shown that printed words are not read as simple linear strings of letters but are parsed into larger units (e.g., Badecker, 1996; Burani & Cafiero, 1991; Caramazza & Miceli, 1990; Prinzmetal, Treiman, & Rho, 1986). Similarly, evidence from both the speed of fingerspelling recognition and the results from memory tasks that require individual letter

reporting indicate that fingerspelled words are not read as a simple linear string of letters but are parsed into larger chunks (Hanson, 1982; Zakia & Haber, 1971). Thus, just as written (and spoken) English words are not processed as a sequence of individual discrete segments, fingerspelled words are not processed as a sequence of individual handshapes.

For written words, Taft (1979, 1987, 2001, 2002) has argued that polysyllabic words are structured in lexical memory in terms of subunits that are defined both on an orthographic and morphological basis: the Basic Orthographic Syllable Structure (BOSS). The BOSS maximizes the amount of information in the first sublexical unit by drawing a structural boundary after all of the consonants that follow the first vowel of the stem morpheme.<sup>1</sup> For example, the BOSS of "cadet" is "cad," "mov" for "movie," and "doct" for "doctor." The BOSS is constrained by phonotactics, such that the BOSS of "kidney" is "kid" not "kidn" because "dn" is not a legal coda in English. Clearly, the BOSS does not correspond to the spoken syllable, and it violates the Maximal Onset Principle in phonology (essentially, make each syllable onset as large as possible; e.g., Selkirk, 1981). Based on data from deaf spellers, Oslon and Caramazza (2004) propose a similar orthographic syllable unit, and they speculate that data from fingerspelling might provide additional evidence for the abstractness of syllabic principles in structuring orthography.

Evidence supporting the psychological reality of the BOSS for reading comes from lexical recognition experiments in which syllables that are compatible with a phonological structure analysis or a BOSS analysis are separated physically by a space or temporally by a rapid succession of a prime segment followed by the word (Taft, 1979, 1987; but see Lima and Pollatsek, 1983). Lexical decision times are faster and more accurate when the word division is congruent with the BOSS (e.g., cad/et) than with the phonological syllable (PS; e.g., ca/det). Chen and Vaid (2007) recently replicated Taft's findings and showed that the BOSS parsing preference was strongest for low-frequency words, which are more influenced by sublexical processing effects (e.g., Seidenberg, 1985). A BOSS parsing strategy may be advantageous when words are read rapidly by sight, without phonological decoding.

Crucially, mature readers tend to read by sight rather than by the more laborious grapheme-to-phoneme conversion process (e.g., Ehri, 2005).

Of particular interest, Taft (2001) reported a stronger preference for reading words with a BOSS division than a PS division for good readers (hearing adults). He suggested that better readers are more sensitive to orthographic structure, whereas poorer readers are more reliant on phonology during silent reading. Thus, although phonological awareness skills are important for hearing children who are learning to read, skilled adult readers may bypass phonological decoding, recognizing words based on orthographically consolidated units stored in memory, such as the BOSS (see Ehri, 1995). Taft (2001) suggests that less-skilled adult readers are more influenced by the pronunciation of words when processing them silently. Deaf readers pose an interesting challenge for this hypothesis because they tend to be poorer readers, but they are unlikely to be more sensitive to phonological structure than hearing readers. If deaf readers exhibit a BOSS preference for reading printed words despite poorer reading skills, it would indicate that poor reading ability in adulthood is not necessarily associated with a reliance on PS parsing or conversely, that a BOSS preference is not always associated with better reading skills.

We conducted two lexical decision experiments based on Taft (1979, 1987) to investigate whether deaf readers prefer to parse printed words based on the PS or the BOSS and whether a PS or BOSS segmentation strategy might be preferred for reading fingerspelled words. We asked the following questions: Do deaf and hearing adult readers exhibit the same parsing preference when reading single words? Do strategies for parsing printed words transfer to fingerspelled words? Does fingerspelling or reading skill correlate with parsing preference?

## Experiment 1: Printed Words

### Methods

*Participants.* Fifty-two deaf signers (26 males) and 32 hearing nonsigners (13 males) participated in Experiment 1. The majority of deaf participants ( $N = 41$ ) were congenitally deaf, and 11 became deaf before 3.5

years of age. Forty-nine participants had severe-to-profound hearing loss, and three had mild-to-moderate hearing loss. All deaf participants used ASL as their preferred language, and 27 were native signers (born into Deaf, signing families), 16 were early signers (exposed to ASL before age seven), and 9 were late signers (exposed to ASL after age 7). The hearing participants reported normal hearing and no knowledge of ASL. No participant reported learning or reading disabilities as a child or currently as an adult.

All participants underwent an Assessment Battery that included the following measures.

“Peabody Individual Achievement Test (PIAT)—Revised (Markwardt, 1989) Reading Comprehension Subtest”: In this subtest, participants are required to read (silently) and remember a sentence, then choose from four pictures the one that best matches the sentence they just read. Items increase in difficulty throughout the test, and the test is discontinued if a participant produces seven consecutive responses containing five errors.

“Vocabulary Subtest of the Shipley Institute for Living Scale”: This subtest consists of 40 multiple-choice questions in which the participant chooses which of 4 words is closest in meaning to a target word (Shipley, 1946).

“Kaufman Brief Intelligence Test—Second Edition (KBIT-2), Matrices Subtest”: The matrices subtest assesses nonverbal intelligence and is a multiple-choice test of nonverbal reasoning (Kaufman & Kaufman, 2004).

“Fingerspelling Reproduction Test” (Science of Learning Center on Visual Language and Visual Learning, 2011): Participants (deaf only) viewed video clips of fingerspelled words ( $N = 45$ ) and pseudo-words ( $N = 25$ ) that were taken from the Spelling and Spelling of Sounds subtests of the Woodcock Johnson III Tests of Achievement. After each clip, the participant was required to repeat (i.e., fingerspell) the item they had just seen. This assessment provided a measure of fingerspelling skill, and performance on this test correlates with ASL skill, as measured by the VL2 ASL-Sentence Reproduction Test (Hauser, Paludneviciene, Supalla, & Bavelier, 2008),  $r = .494$ ,  $p < .001$ , based on data from 66 deaf adults tested in our laboratory.

Participant group characteristics (age, years of education) and mean score on each of the assessment tests are given in Table 1. The deaf participants had significantly lower reading comprehension scores (9th-grade level) than the hearing participants (11th-grade level),  $t(82) = 2.965$ ,  $p = .004$ . The deaf group also had significantly lower vocabulary scores than the hearing group,  $t(82) = 3.595$ ,  $p = .001$ . Thus, the deaf participants were less-skilled readers than the hearing participants. The participant groups did not differ in their scores on the KBIT subtest,  $t < 1$ .

*Materials and procedure.* The stimuli consisted of 30 real words and 30 pseudowords from Taft (1979, 1987) and are listed in the Appendix. The real-word stimuli were relatively low-frequency words (mean frequency per million from CELEX = 16;  $SD = 13$ ). Materials were counterbalanced across participants, such that each word appeared with a BOSS segmentation and with a PS segmentation, but no participant saw the same word twice. Word segmentation was created by first presenting the initial BOSS or PS segment (e.g., “mov” or “mo”) and then the entire word on the computer screen (“movie”) in the same position (i.e., without moving the letter positions of the initial segment). Thus, the initial BOSS or PS segment appears as a prime for word segmentation, following Taft (1987). This temporal-based segmentation method was selected instead of using a space between segments because it was more comparable to the pause method that we used to segment fingerspelled words in Experiment 2.

Stimuli were all lower case (Courier Bold; size = 30) and were presented using Psyscope Build 46 (Cohen, MacWhinney, Flatt, & Provost, 1993) on a Macintosh PowerBook G4 computer with a 15-inch screen. Participants initiated each trial with a button press, which was followed by a 2,000-ms fixation cross.

Participants then saw the “prime” (initial segment of the stimulus item) for 200 ms, followed by the entire stimulus, which appeared on the screen until the participant responded (B key = *yes*; N key = *no*). Participants were instructed to decide as quickly and as accurately as possible whether or not a given item was a real English word. Seven practice items preceded the experimental trials.

Participants were tested either at the Laboratory for Language and Cognitive Neuroscience at San Diego State University or at the University of Iowa, and all were paid for their participation.

## Results

Reaction times (RTs) that were 2 *SDs* above or below the mean for each participant were eliminated from the RT analysis. This procedure eliminated 1.9% of the data for the deaf participants and 1.3% for the hearing participants. For RTs and error rates, we conducted separate  $2 \times 2$  analyses of variance, crossing participant group (deaf, hearing) with segmentation type (BOSS, PS). Only responses to word stimuli were entered into the analyses, and only correct responses were included in the RT analysis. The results are shown in Figure 1.

*Reaction time.* There was a main effect of segmentation type,  $F(82) = 7.525$ ,  $MSE = 5,268$ ,  $p = .010$ . RTs to BOSS-segmented words (mean = 750 ms,  $SE = 17$ ) were significantly faster than to PS-segmented words (mean = 780 ms,  $SE = 18$ ). Response times for deaf participants (mean = 740 ms,  $SE = 21$ ) did not differ significantly from the hearing participants (mean = 790 ms,  $SE = 26$ ),  $F(82) = 2.238$ ,  $MSE = 44,397$ ,  $p = .138$ . There was no interaction between participant group and segmentation type,  $F(82) = 1.648$ ,  $MSE = 5,268$ ,  $p = .203$ , indicating

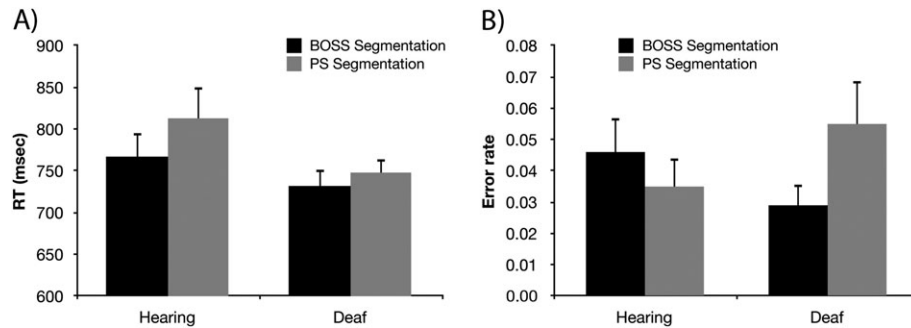
**Table 1** Means for participant characteristics

Participant group	Age (years)	Years of education	PIAT reading comprehension <sup>a</sup>	Shipley vocabulary <sup>b</sup>	KBIT-2 Matrix reasoning	Fingerspelling test
Deaf	28 (5)	17 (2)	85 (10)	28 (5)	110 (11)	84% (11%)
Hearing	25 (6)	15 (2)	90 (6)	32 (5)	111 (17)	N/A

*Note.* *SDs* are given in parentheses. PIAT, Peabody Individual Achievement Test; KBIT-2, Kaufman Brief Intelligence Test—Second Edition; and N/A, not applicable.

<sup>a</sup>Raw score.

<sup>b</sup>Out of 40 items.



**Figure 1** Mean reaction times (RTs) and error rates for hearing and deaf readers for words presented with a Basic Orthographic Syllable Structure (BOSS) segmentation and with a phonological syllable (PS) segmentation. Error bars represent standard error of the mean.

that both groups performed better when words were presented with a BOSS segmentation.

**Error rate.** There was no main effect of segmentation type,  $F < 1$ , and no main effect of participant group,  $F < 1$ . However, there was a trend for an interaction between participant group and segmentation type,  $F(83) = 2.986$ ,  $MSE = .004$ ,  $p = .088$ . For the hearing group, there was no significant difference in error rate for BOSS-segmented words (mean = 4.6%,  $SE = 1.1\%$ ) and PS-segmented words (mean = 3.5%,  $SE = 2.7\%$ ),  $t < 1$ . In contrast, the deaf participants made significantly fewer errors for BOSS-segmented words (mean = 3.0%,  $SE = 0.8\%$ ) than for PS-segmented words (mean = 5.5%,  $SE = 1.2\%$ ),  $t(51) = 2.00$ ,  $p = .049$ .

**Correlation analyses.** We calculated the strength of the BOSS parsing preference for each participant in each group using the following formula:  $(\text{BOSS RT} - \text{PS RT}) / \text{mean RT}$ . For the deaf participants, the strength of the BOSS parsing preference was positively correlated with reading skill, as assessed by both the PIAT reading comprehension subtest (raw score),  $r = .413$ ,  $p = .002$ , and the Shipley vocabulary test,  $r = .297$ ,  $p = .033$ . In contrast, for the hearing participants, there was no significant correlation between the strength of the BOSS parsing preference and reading skill,  $ps > .484$ .

In addition, for both groups faster RTs for words with a BOSS segmentation were associated with higher reading comprehension (PIAT) scores, deaf group:  $r = -.340$ ,  $p = .014$ , hearing group:  $r = -.382$ ,  $p = .031$ . The BOSS RTs did not correlate with

vocabulary scores for either group,  $ps > .113$ . For the hearing participants, but not for the deaf participants, faster RTs for words with a PS segmentation were associated with higher reading comprehension (PIAT) scores,  $r = -.412$ ,  $p = .019$ .

For the deaf participants, fingerspelling ability did not correlate significantly with the strength of the BOSS parsing preference or with RTs for words that have either a BOSS or a PS segmentation,  $ps > .428$ . However, fingerspelling ability did correlate significantly with both reading comprehension (PIAT) scores,  $r = .349$ ,  $p = .011$ , and with Shipley vocabulary scores,  $r = .282$ ,  $p = .042$ .

## Discussion

Both deaf and hearing readers performed better when printed words were segmented (primed) with an orthographically defined first syllable—the BOSS—rather than with a phonologically defined syllable. This effect was somewhat stronger for the deaf readers because it was evident in both RTs and error rates, whereas the effect was only observed with RT for the hearing readers (see Figure 1). Thus, despite being less-skilled readers, the deaf participants showed a preference for BOSS segmentation for printed words. This finding indicates that poor reading ability in adulthood is not necessarily marked by a greater sensitivity to or reliance on phonological syllable structure.

In addition, a BOSS parsing preference was associated with better reading comprehension for deaf participants ( $r = .413$ ), but not for hearing participants. For hearing participants, better reading comprehension scores were correlated with performance (faster RTs)

for words with PS-segmented primes ( $r = -.412$ ), as well as for words with BOSS-segmented primes ( $r = -.382$ ). For deaf participants, better reading skill was associated only with faster RTs for words with BOSS-segmented primes ( $r = -.340$ ). Thus, for the deaf participants, reading skill did not predict performance on phonologically segmented words, whereas for the hearing participants, reading skill predicted performance on both word types. This pattern of results suggests that good deaf readers are more sensitive to orthographic syllable representations, whereas good hearing readers simply perform better on the lexical decision task than poor readers.

One concern about the superiority of BOSS-segmented primes over PS-segmented primes is that BOSS primes contain more letters than PS primes and therefore potentially convey more information about the word, thus speeding lexical recognition. However, Taft (1987) showed that even when the PS division was equally predictive of the lexical item (i.e., the number of words that begin with the PS segment does not differ from the number of words that begin with a BOSS segment), BOSS primes were still more effective. Further, both Taft (1987) and Chen and Vaid (2007) showed that adding a letter to the initial BOSS segment (e.g., “docto” for “doctor”) provided no greater priming (in fact, performance was worse). Thus, a BOSS-segment prime does not just provide more information about the word, but rather it may activate a stored orthographic syllable unit, which speeds visual word recognition.

Parsing preference was not correlated with fingerspelling skill for deaf readers, suggesting that a BOSS-based processing advantage for written words is not related to fingerspelling ability. However, fingerspelling skill was positively correlated with both reading comprehension ( $r = .349$ ) and vocabulary knowledge ( $r = .282$ ). This result indicates that the link between fingerspelling and reading skill observed for children (Hile, 2009; Padden & Ramsey, 2000) continues into adulthood. We suggest that this relationship between fingerspelling and reading ability continues into adulthood because it is bidirectional. That is, reading experience heightens the use of fingerspelling to represent English words, and skilled fingerspelling helps retain print and new vocabulary. One possible

test of this bidirectional relationship is to investigate whether printed words are recoded (or dual coded) as fingerspelled words in short-term memory and similarly, whether fingerspelled words are recoded (or dual coded) as a printed words (possibly in a speech-based code) in short-term memory. We do not expect that deaf adults read text by recoding words into fingerspelling, but it is possible that the association between fingerspelling and print helps retain English vocabulary in memory.

## Experiment 2: Fingerspelled Words

Experiment 2 investigated whether the orthographic-based parsing preference for printed words transfers to reading fingerspelled words. If a fingerspelled word automatically activates a print representation, we hypothesized that the orthographic structure of print might influence segmentation preferences for fingerspelled words. If so, then in a lexical decision task, deaf participants should exhibit faster and more accurate performance for fingerspelled words that contain a pause at a BOSS division (e.g., M-O-V/I-E) than for words with a pause at a PS division (e.g., M-O/V-I-E).

### Methods

*Participants.* Thirty-six deaf signers (19 males) participated in Experiment 2 (mean age = 28 years). All signers also participated in Experiment 1, and the order of experiments was counterbalanced across participants. For this subset of deaf participants, 31 were congenitally deaf and 4 became deaf before 3.5 years of age. Thirty-four participants had severe-to-profound hearing loss and two had mild-to-moderate hearing loss. Seventeen participants were native signers, 11 were early signers, and 8 were late signers. Mean scores and standard deviations on our assessment tasks for this subset of participants were as follows: PIAT (raw score) = 85 ( $SD = 10$ ); Shipley Vocabulary = 28 ( $SD = 5$ ); KBIT-2 = 111 ( $SD = 12$ ); Fingerspelling Reproduction Test = 82% ( $SD = 18\%$ ).

*Materials and procedure.* The fingerspelled stimuli consisted of the same word and pseudoword materials from Experiment 1 (see Appendix) produced by a native deaf signer without mouthing. The signer paused either at the end of a BOSS syllable (e.g., C-A-D ...

E-T) or at the end of a PS (e.g., C-A ... D-E-T). Using Final Cut Express (Apple, Inc.), the length of the pause was digitally manipulated to be 1,000 ms for all stimuli, measured from the first video frame of the “held” fingerspelled letter to when the hand began to transition to the next letter. This digital manipulation was not detectable by participants. We selected a pause duration of 1,000 ms because pilot testing revealed that this pause length was noticeable by signers (unlike a 500-ms pause), and this duration was proportionally analogous to the perceived pause for the print stimuli in Experiment 1. As in Experiment 1, materials were counterbalanced across participants, such that each fingerspelled word appeared with a BOSS segmentation and with a PS segmentation, but no participant saw the same word twice.

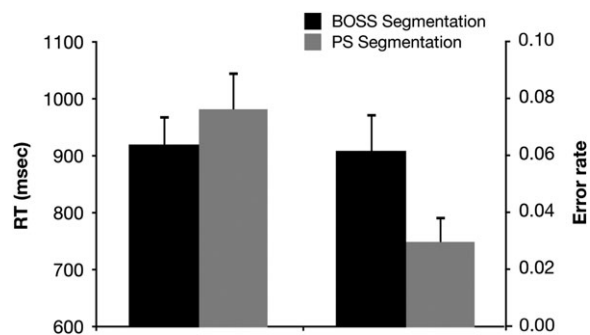
Video clips of fingerspelled words were presented using Psycoscope Build 46 (Cohen et al., 1993) on a Macintosh PowerBook G4 computer with a 15-inch screen. Participants initiated each trial with a button press, which was followed by a 2,000-ms fixation cross. Participants were instructed to decide as quickly and as accurately as possible whether a given item was a real English word, responding with a key press (“B” = *yes*; “N” = *no*). Response times were measured from the end of the fingerspelled word—specifically, from the first frame of the last letter that was produced.

Participants were tested at the Laboratory for Language and Cognitive Neuroscience at San Diego State University, and all participants were paid for their participation.

## Results

RTs that were 2 *SDs* above or below the mean for each participant were eliminated from the RT analysis (this included the rare instance where a participant responded before the end of the word). This procedure eliminated 2.5% of the data. The results are shown in Figure 2.

There was no significant difference in response time between BOSS-segmented fingerspelled words (mean = 921 ms; *SE* = 57 ms) and PS-segmented fingerspelled words (mean = 983 ms; *SE* = 66 ms),  $t(35) = 1.586$ ,  $p = .122$ . However, error rates were significantly lower for words with a PS segmentation (mean = 3.0%; *SE* = 0.9%) than for words with



**Figure 2** Mean reaction times (RTs) and error rates for fingerspelled words presented with a Basic Orthographic Syllable Structure (BOSS) segmentation and with a phonological syllable (PS) segmentation. Error bars represent standard error of the mean.

a BOSS segmentation (mean = 6.2%; *SE* = 1.3%),  $t(35) = 2.254$ ,  $p = .031$ .

We calculated the strength of the PS parsing preference for fingerspelled words using the following formula: (PS error rate – BOSS error rate)/mean error rate (note: if the mean error rate was 0%, then the PS parsing preference = 0). Although there was a strong preference for PS segmentation (mean = 0.47), we did not observe a significant correlation between the strength of this preference and our measures of reading skill,  $p_s > .435$ . However, lower error rates for BOSS-segmented words (but not for PS-segmented words) were associated with higher reading scores on the PIAT,  $r = -.460$ ,  $p = .005$ , and on the Shipley vocabulary test,  $r = .430$ ,  $p = .009$ . Given the low error rate for PS-segmented words (3%), there may not have been enough variability to detect a correlation with reading skill for these words. Finally, fingerspelling ability, as assessed by the Fingerspelling Reproduction Test, did not correlate with error rates or RTs for either BOSS- or PS-segmented words,  $p_s > .169$ . The correlation we reported in Experiment 1 between fingerspelling ability and reading skill held with this subset of deaf participants: PIAT (raw score):  $r = .489$ ,  $p = .002$ ; Shipley vocabulary score:  $r = .342$ ,  $p = .041$ .

## General Discussion

The results of these experiments indicate that different parsing strategies are preferred when reading printed versus fingerspelled words and that the orthographic segmentation strategy for printed words does not transfer to fingerspelled words. This difference

was most evident in error rates (see Figures 1 and 2). Lexical decisions for printed words with an orthographically based (BOSS) syllable segmentation had lower error rates, but for fingerspelled words, error rates were lower for words with a PS segmentation. We hypothesize that the PS segmentation preference for fingerspelled words may arise as a consequence of English mouthing that frequently accompanies the production of fingerspelled words.

Older children and adults frequently mouth the English word when fingerspelling (Marschark, LePoutre, & Bement, 1998), and ASL-English interpreters often mouth fingerspelled words to enhance comprehension (Davis, 1990). Furthermore, even though the sign model for the Fingerspelling Reproduction Test produced fingerspelled words without mouthing, 87% of the deaf participants in this study added English mouthings when fingerspelling the target words. Of even greater interest is that 78% of the deaf signers added mouthings to the pseudowords that are part of this test (e.g., “pash,” “grunches,” “sribbles”). Pseudowords do not have lexical representations, and therefore mouthing must be constructed either from a direct mapping between fingerspelled letters and English phonology or from an indirect mapping from fingerspelled letters to written letters to phonology. The fact that deaf participants often accessed English phonology when fingerspelling supports the hypothesis that there may be a stronger link between fingerspelled words and phonologically defined syllables than between fingerspelled words and orthographically defined syllables.

An interesting question that arises given the results of Experiment 2 is whether syllable boundaries for fingerspelling production might emerge from the properties of mouthing or from changes in the rate of “letter” (handshape) production, as found for handwriting. For example, Kandel, Álvarez, and Valée (2006) asked French and Spanish speakers to write words and pseudowords in uppercase letters, lifting the pen between each letter. Interletter intervals were longer between syllables than within syllables, indicating that the syllable is a high-level unit that constrains the motoric production of handwriting. Similarly, phonological syllables might constitute a processing unit that constrains the manual production of fingerspelled handshapes.

Another related possibility is that the opening and closing mouth movements that are associated with phonological syllables influence the segmentation of fingerspelled words. However, several lines of research suggest that the “hands are the head of the mouth” for sign languages and that manual movements constrain the rhythm or form of mouth movements, rather than the other way round (Boyes-Braem & Sutton-Spence, 2001). Future research on the kinematics of fingerspelling and the associated English mouthings may clarify the role that the phonological syllable plays in the production and comprehension of fingerspelled words.

When reading printed words, orthographic syllable segmentation may represent the optimal parsing strategy for deaf readers (and possibly for hearing readers, as well). Olson and Caramazza (2004) showed that orthographic syllable structure, rather than letter frequency or sensitivity to common letter patterns, explained the pattern of spelling errors made by deaf adults. In addition, the majority of their spelling errors were phonologically implausible, but orthographically legal. Similarly, Olson and Nickerson (2001) found that deaf readers exhibited effects of orthographic syllable structure on a reading task in which participants judged the color of letters in briefly presented words (from Prinzmetal et al., 1986). The number of errors was influenced by groupings of letters defined by syllable structure, not by letter frequency. Further, these effects were not correlated with residual hearing, speech ability, or lip-reading skill. Although deaf readers may be aware of the phonological structure of English, they may not automatically use this knowledge when reading print (for discussion, see Mayberry, del Giudice, & Lieberman, 2011). Deaf readers, and hearing readers as well, appear to process written words based on an orthographic syllable unit that maximizes the amount of information contained in the initial segment of a polysyllabic word (the BOSS). Such orthographically defined units are sensitive to orthotactics, but may violate phonological constraints (see also Badecker, 1996).

Although segmentation preferences for fingerspelling and print may differ, we nonetheless found relatively strong correlations between fingerspelling ability (measured by the Fingerspelling Reproduction Test) and reading ability (measured by the



comprehension subtest of the PIAT and the Shipley vocabulary test). This pattern of results indicates that the association between fingerspelling and print does not lie in shared sublexical parsing units. Rather, we suggest that the association arises from a functional relationship: both systems are used to represent the words of English via alphabetic symbols. Thus, both good readers and good fingerspellers have established strong representations of English, and fingerspelling provides an additional code for retaining and representing English words. Finally, this result demonstrates that the early link between fingerspelling and print observed for deaf signing children (e.g., Padden, 2006) continues into adulthood.

The connection between English phonology and fingerspelling has potential implications for reading instruction for deaf students. For example, fingerspelling accompanied by mouthing may provide an additional visual phonological link in the “chaining” technique used by teachers to create associations between English text, signs, and fingerspelling. This additional link may be particularly important when teachers introduce new English vocabulary (Humphries & MacDougall, 2000). Thus, fingerspelling accompanied by mouthing might help provide a (previously unrecognized) phonological link to print for young deaf readers.

The fact that adult readers (both hearing and deaf) prefer to segment written words based on an orthographically defined syllable supports the hypothesis that mature readers are particularly sensitive to orthographic principles and constraints that govern the sublexical structure of written words. Furthermore, reading comprehension was positively correlated with sensitivity to orthographic structure (i.e., with sensitivity to BOSS segmentation) for the deaf adults in our study. What still remains to be determined is whether and how deaf readers transition from early phases of reading development in which fingerspelling might provide visual phonological cues to print decoding to later phases in which reading is rapid, automatic, and sensitive to orthographic structural principles.

## Note

1. According to this model, morphologically complex words are recognized after they have been decomposed into their individual morphemes; for example, prefixes are initially stripped

off before accessing the stem morpheme (Taft & Forster, 1975). However, all of the words used in this study were monomorphemic, and morphological decomposition was not required.

## Funding

National Science Foundation Grant (BCS 0823576) awarded to K.E. and San Diego State University; Science of Learning Center on Visual Language and Visual Learning at Gallaudet University (National Science Foundation Grant SBE 0541953).

## Conflicts of Interest

No conflicts of interest were reported.

## Acknowledgements

The authors thank Joytsna Vaid for suggesting this study and Marcus Taft for providing the word and pseudoword stimuli. We thank Allison Bassett, Lucinda Batch, Hannah Bowley, Melissa Herzig, Courtney Pollack, Adam Stone, and Isha Vintinner for assistance with stimuli development, data coding, participant recruitment, and testing. We would also like to thank all of the deaf and hearing participants, without whom this research would not be possible.

## References

- Badecker, W. (1996). Representational properties common to phonological and orthographic output systems. *Lingua*, 99, 55–83. doi:10.1016/0024-3841(96)00005-8.
- Battison, R. (1978). *Lexical borrowing in American Sign Language*. Silver Spring, MD: Linstok Press.
- Boyes-Braem, P., & Sutton-Spence, R. (2001). *The hands are the head of the mouth: The mouth as articulator in sign languages*. Hamburg, Germany: Signum.
- Brentari, D., & Padden, C. (2001). A lexicon of multiple origins: Native and foreign vocabulary in American Sign Language. In D. Brentari (Ed.), *Foreign vocabulary in sign languages: A cross-linguistic investigation of word formation* (pp. 87–119). Mahwah, NJ: Lawrence Erlbaum Associates.
- Burani, C., & Cafiero, R. (1991). The role of subsyllabic structure in lexical access to printed words. *Psychological Research*, 53, 42–52. doi:10.1007/BF00867331.
- Caramazza, A., & Miceli, G. (1990). The structure of graphemic representations. *Cognition*, 37, 243–297. doi:10.1016/0010-0277(90)90047-N.
- Chamberlain, C., & Mayberry, R. (2000). Theorizing about the relation between American Sign Language and reading. In C. Chamberlain, J. Morford, & R. Mayberry (Eds.), *Language acquisition by eye* (pp. 221–259). Mahwah, NJ: Lawrence Erlbaum Associates.

- Chen, H.-C., & Vaid, J. (2007). Word frequency modulates the Basic Orthographic Syllabic Structure (BOSS) effect in English polysyllable word recognition. *Language and Cognitive Processes, 22*, 58–82. doi:10.1080/01690960500372717.
- Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: An interactive graphic system for designing and controlling experiments in the psychology laboratory using Macintosh computers. *Behavior Research Methods, Instruments, and Computers, 25*, 257–271. doi:10.3758/BF03204507.
- Conrad, R. (1979). *The deaf school child*. London: Harper & Row.
- Davis, J. (1990). Linguistic transference and interference: Interpreting between English and ASL. In C. Lucas (Ed.), *Sign language research: Theoretical issues* (pp. 308–321). Washington, DC: Gallaudet University Press.
- Ehri, L. (1995). Phases of development in learning to read words by sight. *Journal of Research in Reading, 18*, 116–125. doi:10.1111/j.1467-9817.1995.tb00077.x.
- Ehri, L. (2005). Development of sight word reading: Phases and findings. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 135–154). Malden, MA: Blackwell Publishing.
- Hanson, V. L. (1982). Use of orthographic structure by deaf adults: Recognition of fingerspelled words. *Applied Psycholinguistics, 3*, 343–356. doi:10.107/S0142716400004276.
- 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*, 172–183. doi:10.1093.deafed/enm003.
- Hauser, P., Paludneviciene, R., Supalla, T., & Bavelier, D. (2008). American Sign Language—Sentence Reproduction Test: Development and implications. In R. M. de Quadros (Ed.), *Sign language: Spinning and unraveling the past, present and future* (pp. 160–172). Petrópolis, Brazil: Arara Azul.
- Hile, A. E. (2009). *Deaf children's acquisition of novel fingerspelled words (Unpublished doctoral dissertation)*. University of Colorado, Boulder.
- Hirsh-Pasek, K. (1987). The metalinguistics of fingerspelling: An alternate way to increase reading vocabulary in congenitally deaf readers. *Reading Research Quarterly, 22*, 455–474.
- Humphries, T., & MacDougall, F. (2000). "Chaining" and other links: Making connections between American Sign Language and English in two types of school settings. *Visual Anthropology Review, 15*, 84–94. doi:10.1525/var.2000.15.2.84.
- Jusczyk, P. W. (1997). *The discovery of spoken language*. Cambridge, MA: MIT Press.
- Kandel, S., Álvarez, C. J., & Valée, N. (2006). Syllables as processing units in handwriting production. *Journal of Experimental Psychology, 32*, 18–31. doi:10.1037/0096-1523.32.1.18.
- Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test, second edition, manual*. Minneapolis, MN: NCS Pearson.
- Lima, S. D., & Pollatsek, A. (1983). Lexical access via an orthographic code? The Basic Orthographic Syllable (BOSS) reconsidered. *Journal of Verbal Learning and Verbal Behavior, 22*, 310–332. doi:10.1016/S0022-5371(83)90215-3.
- 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*, 671–684. doi:10.1037/h0031226.
- Markwardt, F. C. (1989). *Peabody Individual Achievement Test—Revised manual*. Circle Pines, MI: American Guidance Service.
- Marschark, M., LePoutre, X., & Bement, L. (1998). Mouth movement and signed communication. In R. Campbell, B. Dodd, & D. Burnham (Eds.), *Hearing by eye II: Advances in the psychology of speechreading and auditory-visual speech* (pp. 245–266). East Sussex, UK: Psychology Press.
- Mayberry, R. I., del Guidice, 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*, 164–188. doi:10.1093/deafed/enq049.
- Olson, A. C., & Caramazza, A. (2004). Orthographic structure and deaf spelling errors: Syllables, letters, and speech. *The Quarterly Journal of Experimental Psychology, 57A*, 385–417. doi:10.1080/02724980343000396.
- Olson, A. C., & Nickerson, J. F. (2001). Syllabic organization and deafness: Orthographic structure or letter frequency in reading? *The Quarterly Journal of Experimental Psychology, 54A*, 421–438. doi:10.1080/713755975.
- 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.
- 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.
- Padden, C. A., & Gunsauls, D. C. (2003). How the alphabet came to be used in sign language. *Sign Language Studies, 4*, 10–33.
- Padden, C. A., & Ramsey, C. (1998). Reading ability in signing deaf children. *Topics in Language Disorders, 18*, 30. doi:10.1353/sls.2003.0026.
- Padden, C. A., & Ramsey, C. (2000). American Sign Language and reading ability in deaf children. In C. Chamberlain, J. Morford, & R. Mayberry (Eds.), *Language acquisition by eye* (pp. 221–259). Mahwah, NJ: Lawrence Erlbaum Associates.
- Perfetti, C. A., & Sandak, R. (2000). Reading optimally builds on spoken language. *Journal of Deaf Studies and Deaf Education, 5*, 32–50. doi:10.1093/deafed/5.1.32.
- Prinzmetal, W., Treiman, R., & Rho, S. H. (1986). How to see a reading unit. *Journal of Memory and Language, 25*, 461–475. doi:10.1016-0749-596X(86)90038-0.
- Science of Learning Center on Visual Language and Visual Learning. (2011). *Fingerspelling Reproduction Test [computer video] (Unpublished instrument)*. Washington, DC.
- Seidenberg, M. S. (1985). The time course of phonological code activation in two writing systems. *Cognition, 19*, 1–30.
- Selkirk, E. O. (1981). English compounding and the theory of word-structure. In M. Moortgat, H. Van der Hulst, & T. Hoestra (Eds.), *The scope of lexical rules*. Dordrecht, (pp. 229–277) The Netherlands: Foris.
- Shipley, W. C. (1946). *Institute of Living Scale*. Los Angeles, CA: Western Psychological Services.

- Taft, M. (1979). Lexical access via an orthographic code: The Basic Orthographic Syllabic Structure (BOSS). *Journal of Verbal Learning and Verbal Behavior*, 18, 21–39. doi:10.1016/S0022-5371(79)90544-9.
- Taft, M. (1987). Morphographic processing: The BOSS re-emerges. In M. Coltheart (Ed.), *Attention & performance XIII* (pp. 265–279). London: Lawrence Erlbaum Associates.
- Taft, M. (2001). Processing of orthographic structure by adults of different reading ability. *Language and Speech*, 44 (Pt 3), 351–376. doi:10.1177/00238309010440030301.
- Taft, M. (2002). Orthographic processing of polysyllabic words by native and nonnative English speakers. *Brain and Language*, 81, 532–544. doi:10.1006/brin.2001.2545.
- Taft, M., & Forster, K. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior*, 5, 71–89. doi:10.1016/S0022-5371(75)80051-X.
- Zakia, R. D., & Haber, R. N. (1971). Sequential letter and word recognition in deaf and hearing subjects. *Perception and Psychophysics*, 9, 110–114. doi:10.3758/BF03213041.

## Appendix

Phonological syllable segmentation	Basic Orthographic Syllable Structure segmentation	Pseudowords
an/tics	ant/ics	bac/ertate
an/tique	ant/ique	ba/tron
bas/ket	bask/et	blan/ger
car/pet	carp/et	cal/tor
cir/cuit	circ/uit	cas/let
cir/cular	circ/ular	cof/iste
clus/ter	clust/er	fe/nude
dic/tate	dict/ate	fin/ten
dras/tic	drast/ic	fob/le
du/bious	dub/ious	ful/ivant
fa/tal	fat/al	ga/lade
fi/ber	fib/er	gor/nat
fla/vor	flav/or	harp/ious
for/mal	form/al	larst/en
gey/ser	geys/er	lem/ot
i/deal	id/eal	lor/ket
jour/nal	journ/al	mart/ol
mo/vie	mov/vie	me/cret
mys/tery	myst/ery	ming/er
na/tive	nat/ive	mus/love
pi/racy	pir/acy	na/bulate
poi/son	pois/on	po/lisate
pu/pil	pup/il	rac/tious
rou/tine	rout/ine	san/lite
spec/tacle	spect/acle	sul/ter
spi/der	spid/er	tarm/ate
splend/did	splend/id	tib/eral
thun/der	thund/er	to/lade
tur/bulent	turb/ulent	trom/ble
vi/rus	vir/us	wil/dow