This paper examines the concept of phonological awareness (PA) as it relates to the processing of American Sign Language (ASL). We present data from a recently developed test of PA for ASL and examine whether sign language experience impacts the use of metalinguistic routines necessary for completion of our task. Our data show that deaf signers exposed to ASL from infancy perform better than deaf signers exposed to ASL later in life and that this relationship remains even after controlling for the number of years of experience with a signed language. For a subset of participants, we examine the relationship between PA for ASL and performance on a PA test of English and report a positive correlation between ASL PA and English PA in native signers. We discuss the implications of these findings in relation to the development of reading skills in deaf children.

Phonological awareness (PA) commonly refers to a metalinguistic awareness of the sound structure of a language—our conscious ability to detect and manipulate language sounds (Liberman & Shankweiler, 1985; Wagner & Torgesen, 1987). PA is not a unitary construct but includes a range of skills which demonstrates a language user’s sensitivity to different aspects of the sound structure of word forms, ranging from individual phonemes (i.e., phonemic awareness), to syllabic constituents (e.g., onset, rime, and codas), morphemes, and words themselves. PA is one element of the broader construct of phonological processing skills that includes phonological memory and rapid naming (Wagner & Torgesen, 1987).

Tasks that reveal PA include the ability to rhyme words, to hear that different words start with the same or different sounds, or tell the number of phonemes (sounds) included in single words. Tasks involving the blending, deleting, substituting, or moving of individual phonemes within or between words are common assessments of PA. Being able to identify separate words in a spoken sentence, or to hear the two components of a compound word, or to hear and separate syllables also requires PA.

Since Wagner and Torgesen’s (1987) seminal review which supported a causal role for PA in learning to read, a plethora of research continues to document the relationships between phonological skills, especially PA, and the acquisition of reading (but see Castles & Coltheart, 2004). A recent meta-review examined relationships among three of the most widely studied measures of children’s phonological skills (phonemic awareness, rhyme awareness, and verbal short-term memory) and reports a pivotal role of phonemic awareness as a predictor of individual differences in reading development (Melby-Lervåg, Lyster, & Hulme, 2012). Anthony and Francis (2005) stated that PA and its relation to literacy exist in all alphabetic languages that have been examined (see also Goswami, 2008).

The question of how and whether deaf and hard of hearing (DHH) children develop a sound-based PA and whether this is causally related to the development of reading in this population has been an area of active research (see, e.g., Easterbrooks, Lederberg, Miller, Bergeron, & Connor, 2008; McQuarrie & Parrila, 2009; Mayberry, del Giudice, & Lieberman, 2011; Miller, 1997; Sterne & Goswami, 2000; Trezek & Malmgren, 2005; Wang, Trezek, Luckner, & Paul, 2008). Given the great heterogeneity in language experiences, educational instruction, etiologies of hearing loss, and variability in audiological profiles of DHH students, it is perhaps not surprising that there is a wide range of data...
and inferences drawn about the importance of spoken language PA in learning to read.

This paper takes a departure from this tradition and introduces the concept of PA as it relates to American Sign Language (ASL). We present a newly developed test of ASL PA and examine whether deaf signers show differential abilities on this measure. We then evaluate the role of language experience on ASL PA.

Within the deaf population, there are many individuals who rely upon visual manual languages such as ASL for communication. Linguists have shown that signed languages are fully expressive human languages with grammatical processes that have developed largely independent of the influence of spoken languages. Linguists have argued for the existence of a phonological level of language structure in signed languages that include representations of features, segments, and syllables and have described productive phonological processes as well as language-specific constraints of sign formation (Battison, 1978; Brentari, 1998; Corina, 1996; Perlmutter, 1992; Sandler & Lillo-Martin, 2006).

While the theoretical construct of sign language phonology has been useful in the description of signed language grammars, there remain significant questions as to how signers make use of these theoretically motivated categories during online processing and whether signers are sensitive to these abstract levels of description (see Corina & Hildebrandt, 2002 for some discussion).

Phonological Processing in ASL

Psycholinguists have examined whether deaf users of signed languages are sensitive to the structural parameters of signs (e.g., handshape, location, and movement) during sign language recognition. Using primed lexical decision paradigms, researchers have examined whether there are processing advantages when viewing two temporally adjacent signs that share formational parameters (i.e., signs sharing one or more parameters, e.g., two signs sharing the same handshapes). Results from these endeavors have been mixed. For example, Corina and Emmorey (1993) reported inhibitory effects for targets sharing an articulatory location with primes, no effects for shared handshapes and a facilitatory effect for shared movements. Corina and Hildebrandt (2002) investigated movement and location priming at 500- and 100-millisecond (ms) inter-stimulus interval (ISI) lags. No phonological priming was observed at the 500 ISI lag, while inhibitory marginally significant trends were observed both for Location and Movement at the 100 ISI lag. Further, Dye and Shih (2006) found some evidence of facilitatory phonological priming in native signers for signs that shared a common location and/or movement. Importantly, these effects were not observed when primes were pseudosigns, suggesting that phonological priming is a lexical phenomenon. A series of studies conducted with Lengua de Signos Española (LSE) has examined the interaction between sign similarity and frequency (Carreiras, Gutiérrez-Sigut, Baquero, & Corina, 2008). These studies reported that for neighborhoods defined by location, low-frequency signs were recognized faster in sparse neighborhoods. A different pattern was observed for neighborhoods defined by handshape. Here, low-frequency signs were recognized more quickly in dense neighborhoods. This work provides more evidence that formational/phonological similarity interacts with lexical constructs, including the composition of lexical neighborhoods.

Two recent event-related potential studies examined the time course of lexical activation for signs within a sentence context and reported effects for shared phonological properties. Grosvald, Gutierrez, Hafer, and Corina (2012) examined ERP data collected for target words that were semantically appropriate (baseline), semantically inappropriate, or a pseudosign that was formationally possible but a nonexisting ASL sign. Similar to what has been reported for spoken languages (Bentin, 1987; Bentin, McCarthy, & Wood, 1985; Hagoort & Kutas, 1995; Holcomb & Neville, 1990; Kutas & Hillyard, 1980), relative to the appropriate ending conditions, the two anomalous sign conditions elicited a greater negativity at approximately 400 ms after the stimulus onset. Moreover, the formationally possible nonsigns produced a greater negativity than the semantically inappropriate sign. Importantly, the response to the pseudosign condition was clearly distinct from a fourth condition in which the critical ending sign was replaced with a nonlinguistic gesture, which bore no systematic relationship to the phonotactic properties of ASL. Thus, deaf participants showed
a clear linguistic sensitivity to the sign properties of the stimuli. In a separate sentence processing paradigm, Gutierrez and colleagues recorded ERPs to critical signs that were consistent with the sentence context (baseline) (e.g., Last-night I had a drink of WINE, it was delicious!) or were semantically (s) and phonologically (p) consistent with the expected baseline target (e.g., BEER, +s, +p). Additionally, items could share the expected location of the baseline sign, but were semantically unrelated (e.g., CANDY, −s, +p), or were semantically related to the baseline form but had a phonological form that differed from the expected sign target (e.g., MILK, +s, −p). Finally, a fifth condition tested words that were completely unrelated to the sentence context (e.g., JUDGE, −s, −p). The most pertinent results for the present paper are that the ERP responses showed an early sensitivity to phonological and semantic mismatches. Evidence for an early effect of semantic preactivation of plausible candidates (150–250 ms) was followed by a negativity associated with lexical selection (350–450 ms) for only phonologically related (−s, +p) and for only semantically related (+s, −p) signs. In the 450–600 ms window, all conditions showed an increased N400 with respect to the expected ending, suggesting greater difficulty in semantic integration with the established context. Taken together, these studies demonstrate electrophysiological evidence for stages of language processing that involve sensitivity to formational properties of ASL signs; these effects may be observed quite early in language processing and are clearly distinct for nonlinguistic gesture processing (Grosvald et al., 2012; Gutierrez, Williams, Grosvald, & Corina, 2012).

These online psycholinguistic tests suggest that deaf participants are differentially sensitive to ASL phonological structure, and these results provide evidence in favor of a parameter-based lexical organization (e.g., Location, Movement, and Handshape) that appears to be sign specific. Additional work is required to fully understand the time course of these activations and how the combinatorial aspects of shared phonological structure may produce inhibition in some cases (e.g., shared locations) and facilitation in others (e.g., shared movements). In addition, the role of language experience, which often interacts with these effects, has yet to be fully understood.

A different approach to the study of signer’s appreciation of the phonological properties of signs comes from off-line judgment studies and observations of culturally accepted language play. In one of the first investigations of explicit PA for ASL, Hildebrandt and Corina (2002) reported that similarity judgments of signs sharing two sign parameters (i.e., handshape and movement) produced more consistent similarity judgments than sign pairs sharing only one parameter. Both deaf signers and hearing sign-naive participants judged signs that share movement and location (+M, +L) as the most similar, indicating that this combination of parameters enables a robust perceptual grouping. This combination of parameters is noteworthy as theories of ASL syllable structure have proposed that movement and location features as the most similar accords with the observation that languages commonly capitalize on salient perceptual distinctions as a basis for linguistic distinctions.

Further consideration of the response patterns of deaf signers and hearing nonsigners suggest that under some circumstances, tacit knowledge of ASL syllable structure may override the purely perceptual factors in these similarity ratings. This is seen in the different rankings of deaf and hearing participants similarity judgments across the data set. Specifically, hearing nonsigners similarity ratings appear to rely heavily on the presence (or absence) of shared movements across sign pairings. Hearing participants rated sign pairs sharing movement and location (+M, +L) as the most similar followed next by (+M, +H) sign pairs, while sign pairs sharing location and handshape (+L, +H) were judged as least similar. This ranking of similarity judgments suggests that shared movement is quite salient for nonsigners. In contrast, while deaf signers also judged sign pairs sharing (+M, +L) parameters as most similar, they ranked both (+L, +H) and (+M, +H) sign pairs as equally similar. One way to explain this pattern of data is that native signers are tapping into linguistically motivated groupings in their similarity judgments. For signers only sign pairs that share (+M, +L) parameters
constitute a sensible syllabic grouping, while sign pairs sharing (+L, +H) or (+M, +H) parameters are equally ill-formed (i.e., they do not constitute coherent linguistic groupings). Hearing participants who are not attuned to this level of phonological representation are driven by the surface characteristics of the sign pairs and principally the saliency of the movement. Thus for native signers the knowledge of ASL syllable structure may override purely perceptual factors (i.e., the saliency of shared movement) in their consideration of similarity judgments.

Clues to the privileged groupings within a language can often be observed in stylized uses of language such as poetry, language games, and song. Signed languages are no exception. Klima and Bellugi (1979) investigated examples of sign poetry (or “art sign”) as a specialized use of ASL. They observed that a similar handshape may be used throughout a poem, a device analogous to the spoken language phenomenon of alliteration (where each word shares a similar initial sound). In sign poetry, there is a great deal of attention to the flow and rhythm of the signs, much like artistic manipulation of the melodic line in spoken poetry (Blondel & Miller, 1998; Rose, 1992). Often, the locations and movements of signs are manipulated to create cohesiveness and continuity between signs. Valli (1990) also noted recurrence of similar nonmanual features throughout a poem. Signs, like spoken and written words, may overlap or be shortened or lengthened to create a rhythmic pattern. These devices are combined to create strong visual imagery unique to visual-gestural languages (Cohn, 1986). Examples of language games in ASL include “ABC stories” and “proper name stories.” In these games, a story is told with the constraint that each successive sign in the story must use a handshape drawn from the manual alphabet in a sequence that follows the alphabet or spells a proper name. Signed cheerleader fight songs also evidence repetition of rhythmic movement patterns and handshape alliteration.

Taken together, these examples demonstrate that sign forms exhibit component structures that are accessible to independent manipulation (e.g., handshapes) and provide hints of structural relatedness (e.g., similar movement paths). However, it should be noted that there is no generally accepted notion of a naturally occurring structural grouping of sign properties that constitute an identifiable unit in the same sense that a “rhyme” does for users of spoken languages. While several researchers have used the term “rhyme” to describe phonemic similarity in signs (Klima & Bellugi, 1979; Valli, 1990), it remains to be determined whether a specific combination of structural properties serve this function.

Phonological Processing and Language Acquisition

There is considerable variability of sign language exposure and experience in the adult deaf population (Padden & Humphries, 1988). Only about 10% of deaf individuals are exposed to sign language from birth from their deaf signing parents. The majority of deaf signers may experience delays in sign language acquisition, with first exposure limited to a preschool or elementary school setting. Furthermore, it is not uncommon for deaf adults, whose early language experience was based on oral education, to learn sign language as teenagers. The impact of the differential age of exposure to a sign language has been repeatedly observed in lexical processing studies of signed language (Carreiras et al., 2008; Corina & Knapp, 2009; Emmorey & Corina, 1990; Emmorey, Corina, & Bellugi, 1995; Hildebrandt & Corina, 2002; Mayberry & Eichen, 1991; Mayberry & Fischer, 1989; Mayberry & Witcher, 2005; Morford & Carlson, 2011, Morford, Grieve-Smith, MacFarlane, Staley, & Waters, 2008). Across many studies, deaf signers who have acquired sign language after infancy (but nevertheless report using a signed language like ASL as their preferred and dominant language) perform more slowly on lexical tasks and often show characteristic patterns of performance which, in part, suggest greater attention to surface-level properties of sign forms. One interpretation of these findings is that nonnative signers are less efficient in decoding the phonological forms of signs than are native signers, for whom this stage of processing takes place in a more automatic fashion.

A recent study by Morford et al. (2008) refines this interpretation and suggests that late learners may be responsive to phonetic detail that native signers have learned to ignore. Based on these findings we speculated that deaf participants’ PA, as defined by our task, may also show effects of age of exposure, with
late exposure to ASL leading to poorer performance, and native signers showing more facility.

ASL Phonological Awareness Test

Accruing evidence suggest that deaf signers are sensitive to aspects of sign formation, especially in online measures of lexical processing. However, the degree to which a metalinguistic PA for signed language exists and whether the age of exposure to sign language differentially interacts with this ability is largely unknown. In an effort to further explore PA for ASL, we constructed a novel sign segmentation task, which requires the explicit manipulation of structural properties of ASL signs. Facility in this task, we believe, provides one measure of PA for a signed language. Our main question of interest was whether there were differential abilities in performing this explicit phonological decision task as a function of age of sign exposure. Second, for a subset of our participants we examine the relationship between ASL PA and English PA tests. Finally, we discuss the implications of our results as it relates to emerging theories of skilled reading in profoundly deaf individuals.

Our PA task required participants to view video clips of two pseudosign forms. Based on these forms, they were asked to isolate handshape, movement, and location properties of the two pseudosigns and combine them in a fashion that yielded an existing ASL sign. An analogous task in English would be, “Please listen to two pseudowords; ‘krom’ and ‘leete’, and using components of these pseudowords create a possible common English word.” For example, one could take the onset of the first word /kr/, the nucleus of the second word /i/, and the coda consonant of the first word /m/ to create the word /krim/ “cream.” Note that words like “Crete” or “meet” might also be allowable answers. To delimit the choices in the ASL version, for each trial, three real signs were provided as possible answers, only one of which fully satisfied the requirements for recombining properties of the pseudosigns. The foils, while both possible signs, included elements of the nonsigns but did not fully satisfy combinatorial criteria.

One necessarily confronts several choices in the development of video-based tests for assessing ASL PA in this manner. Extensive pilot testing (not reported) was used to determine the final version of the experiment. One major issue is how to present the initial nonsigns, the correct sign answer, and the two foils in a manner that does not overwhelm perceptual and memory capacities of the participants. In the implementation of the test reported here, participants first pressed a spacebar on a laptop computer (Dell latitude D620) running PRESENTATION 15.0 to begin the experiment. This resulted in a display of five simultaneously occurring signs, the two nonsign appearing at the top of the screen and the three possible answers on the bottom half of the display these were labeled “A,” “B,” and “C.” A screen shot of a trial can be seen in Figure 1.

Each time a participant pressed the spacebar, all five videos would play simultaneously. Participants were encouraged to press the spacebar as many times as they needed to examine the two nonsign forms and evaluate the potential answers. This procedure ensured that our task was not simply an assessment of perceptual or memory load of monitoring simultaneously played videos, but was a reflection of the conscious effort required to solve this metalinguistic puzzle. Our intuitions suggested that individuals, for whom sign-component segmentation and mental manipulation of sign forms were more facile, would require fewer presses of the spacebar before they responded. As such, in addition to tabulating accuracy scores, we evaluated the utility of using the numbers of spacebar presses as an additional dependent variable in our design. While there are many other possible scenarios for assessing PA in a sign language, this task provided an important and informative starting point in our ongoing investigations.

Participants

Eight-seven severely to profoundly deaf participants were individually tested and were divided into three groups based upon self-reported exposure to sign language, school history, and other pertinent demographic information. Thirty-one participants (17 female, 14 male) (mean age 31.8, range 20–45) were considered native signers, meaning that they either learned ASL from deaf or hearing native signing parents, or in 4 cases, from an older deaf signing sibling.
Forty participants (21 female, 19 male) (mean age 31.7, range 21–50) were considered early exposed. In these cases, participants reported exposure to sign language in an elementary school setting prior to age 8. Sixteen participants (10 female, 6 male) (mean age 38.4, range 23–50) were considered late exposed and reported sign language exposure after age 8 and largely in their teenage years. Participants were asked to self-report hearing loss, available data are reported in Table 1.

Materials and Methods

A native female signer served as our sign model and executed all signs and nonsigns. All stimuli were filmed using a Sony DVCAM (model HXR-NX5U) against a green screen background in the laboratory’s studio. The stimuli were edited with Final Cut Pro (ver. 7.1) and the green background that was digitally replaced with a neutral color for clarity purposes. All sign forms were closely edited as is customary in our laboratory, specifically stimuli were edited to remove noncritical transitional movements. Liddell and Johnson (1989) discuss the fact that phonetically, signs often exhibit a brief stasis where a sign’s acceleration is effectively zero. On video with 30 frames per second encoding, this appears as a moment in which the intended target handshape of the sign is clearly articulated and nonblurred. In our laboratory’s editing scheme, our sign stimuli started two frames prior to this initial hold segment of the sign. The ending frame of each sign stimulus was chosen as the point at which the target handshape began to fall out of its intended form. We applied this same approach to the editing of the pseudosign as well.

Based upon pilot testing, the pseudosign “inputs,” were composed of two nonexisting ASL signs that contained the three specific parameters (handshape, movement, and location) needed to formulate an actual ASL sign. In the pseudosign pairs the three parameters were grouped into two different categories; handshape and movement in one pseudosign and the location parameter signaled in the other, or location and movement presented in one pseudosign while the handshape parameter was present in the other pseudosign. Ordering of these types of trials was balanced across the experiment via a fixed random order as was the side of presentation for the nonsign pairs.

Prior to the actual test, all participants viewed a Powerpoint presentation that explained the task and provided explicit examples of how the task was to be completed, highlighting how features of individual signs could be recombined to create a new sign. In addition to written instructions, ASL instructions were provided to all participants as needed during
this practice time-period. Practice trials differed from the actual test items. After watching the explanation, participants received a practice trial and the examiner clarified any question the participants had and in some cases repeated the pertinent examples. All participants demonstrated that they were able to perform the manipulation prior to beginning the actual test.

The test proper consisted of 20 distinct sign trials, however due to a technical error, data from the first trial were only intermittently captured; thus all results were predicted on the 19 trials that all participants received. The order of presentation was fixed random order, with the constraint that no more than two of the same correct answer locations followed each other. Testing was administered individually and took roughly 10–15 min to complete.

Participants were given the following instructions:

In this test, you will be asked to combine sign components (handshapes, locations, and movements) from two signs to create a new sign. Which sign on the bottom of the screen can be made from combining the components (handshapes, locations, movements) of the two signs shown on top of the screen? Select A, B, or C to indicate your choice. If you would like to view the videos again, press the SPACEBAR. You may see the videos again as many times as needed. Please try to answer with as few repetitions as possible. After you have selected the video, press ENTER to confirm your choice.

Accuracy Analysis

Each participant’s data was scored for accuracy (19 possible correct) and number of repetitions used per trial. Participants who scored less than six correct trials were excluded from this and subsequent analyses (three natives, three early, and one late signer). For the accuracy analysis this resulted in usable data from 28 native signers, 37 early signers, and 15 late signers.

Accuracy data were analyzed using ANOVA with between participant’s factor of Group (Native, Early, and Late). Effects of language experience were evaluated as planned comparisons. The dependent variable for accuracy was the number of correct trials out of 19.

Results

The ANOVA revealed a main effect of Group ($F(2, 77) = 6.309, \eta^2 = .141, p < .003$). As shown in Figure 2, native signers were most accurate ($M = 16.1, 95\% CI [14.98, 17.22]$), followed by the late signers ($M = 14.0, 95\% CI [12.46, 15.53]$) with early signers showing the least accuracy ($M = 13.5, 95\% CI [12.53, 14.48]$). Planned comparisons revealed that native signers’ accuracy was significantly different from both early signers (Native – Early, $M = 2.594, p < .001$), and was different from late signers’ accuracy (Native – Late, $M = 2.107, p < .03$). Early and late signers did not differ significantly from each other (Early – Late, $M = .486, p = .595$).

Repetition Analysis

For the repetition analysis, the dependent measure was the mean number of repetitions a participant used before providing a correct response. Outlier replacement was used in cases where a participants repetitions for a given trial exceeded three standard-deviations from the mean number of repetitions of all participants ($M = 5.29$ repetitions, $SD = 3.03$). Individual outlier data points were replaced with the mean value for that group’s response to that trial (less than 1.25% of all trials). Finally, any participant whose repetition data required the replacement of three or more trials in this manner was further excluded from the final analysis (one native, five early, and five late). This conservative approach was taken to ensure that the participants whose data were considered in this repetition analysis maintained an accurate level of performance and excluded trials with spurious repetitions that likely do

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Participants</th>
<th>No. of subjects reporting hearing status</th>
<th>dB loss [range] SD left ear</th>
<th>dB loss [range] SD right ear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native</td>
<td>31 (17 female)</td>
<td>15</td>
<td>87 [50–120] 20.07</td>
<td>94.07 [45–120] 12.07</td>
</tr>
<tr>
<td>Early</td>
<td>40 (21 female)</td>
<td>13</td>
<td>98.16 [90–120] 11.19</td>
<td>96.07 [70–120] 14.33</td>
</tr>
<tr>
<td>Late</td>
<td>16 (10 female)</td>
<td>15</td>
<td>86.64 [55–120] 20.34</td>
<td>84.6 [55–120] 20.64</td>
</tr>
</tbody>
</table>

Table 1: Participants age and reported hearing loss, dB [range] SD
not reflect time on task (e.g., occasionally participants forgot that a carriage return was required to advance to the next trial, rather than a repressing of the spacebar). The following analysis is based on 27 native signers, 32 early signers, and 10 later signers.

Results
Examination of the ANOVA for the repetition data revealed no significant differences, Group (F(2,66) = 1.85, MSE = 2.88, p = .185), native signers (M = 5.12, SD = 0.79), early signers (M = 5.29, SD = 0.70), late signers (M = 4.12, SD = 0.84). Planned comparisons confirmed the lack of group differences (all p’s > .1).

Discussion
The data indicate that overall, native signers were generally more accurate than early and late ASL exposed deaf signers on our ASL PA task. Planned comparisons revealed native signers were significantly more accurate than both early ASL exposed deaf signers and late-exposed signers. Early- and late-exposed signers performed nearly equivalently, with similar accuracy scores on this PA test of ASL. The accuracy of early- and late-exposed signers did not differ significantly from one another. This result suggests that exposure to ASL from infancy may provide a basis for the development of metalinguistic awareness for ASL as measured by this test which required participants to mentally recombine phonological parameters from two pseudo-signs to create a possible sign. The data from early and late ASL exposed nonnative deaf signers is consistent with previous studies that have shown that deaf individuals who have experienced delays in the acquisition of sign may have trouble processing surface-level formalional properties of signs. The present finding adds to a growing number of studies that have shown that nonnative learners of sign language, while highly fluent users of sign, may experience processing inefficiencies at the level of phonological structure (Mayberry & Fischer, 1989; Morford et al., 2008). It is interesting to note that many of the studies which find language experience dependent processing differences have been online paradigms that required rapid real-time responses to sign forms. What is particularly striking in the present case is that despite the off-line nature of our PA task, we continue to observed differences in the accurate mental manipulation of sign language phonological forms in early and native signers.

While the present paradigm showed group differences in accuracy, examination of the number of stimulus repetitions required before participants made these judgments did not differentiate between the three groups. Though unexpected, this is an important finding for several reasons. First, to the extent that the number of bar-presses serves as a proxy for time on task, it makes it less likely that the native signers
were more accurate because they uniformly chose to spend more time with the task, as was permitted by the design. Second, while it appears that the late learners were more willing to commit to a decision based upon fewer viewings of the stimuli; these individuals were no less accurate than the early exposed signers. However as we did not collect absolute duration of the time on task across participants, these observations must await further confirmation. Third, the data suggest that our intuitions about the usefulness of repetition as a dependent variable were incorrect. This lack of predictive value of stimulus-display repetition may be important in consideration of the development of future measures of ASL processing which aspire to overcome perceptual and cognitive demands of multiple video images of sign forms through repeated presentation.

These data suggest that early ASL exposure affords advantages in the mental manipulation of sub-lexical properties of ASL sign formation. One possible explanation for this result is that native language exposure creates robust visual-perceptual categories in the developing brain. Studies of spoken language have repeatedly shown that native language speech categories are formed early in infancy given sufficient exposure to a dominant language (Kuhl et al., 2006; Werker, Yeung, & Yoshida, 2012). One may speculate that such well-etched categories provide representational “footholds” for subsequent metalinguistic tasks that make reference to these components as in the present study.

Effects of Age of Acquisition

An alternative account of this data posits that it is the cumulative time using ASL, rather than the initial age of exposure, which determines the development of metalinguistic abilities. Under this interpretation, early and late learners of ASL have not had the same absolute magnitude of time with the language to develop metalinguistic awareness. To address this issue, we examined a subset of signers matched for duration of sign language exposure. From our data we were able to identify an older cohort of early ASL learners (n = 16) who had 18 or more years of ASL exposure (mean age = 35 [range 21–50], mean years of ASL exposure = 28.18 [range 18–37]; mean dB loss: left ear 93.15 [range 45–120], right ear: 83 [range 50–120]) and matched as close as possible a group of 16 native signers who had the same duration of ASL exposure (Mean age/years of ASL exposure = 28.75 [range 20–45], mean dB loss left ear: 94 [range 90–120], right ear: 92.75 [range 81–110]). Years of exposure did not differ between groups (p = .843). We used a one-way ANOVA to evaluate PA accuracy for the two groups. Results indicated that the native signing group was more accurate than the later exposed participants (Native Exposure M = 16, 95% CI [14.575, 17.425]); Late Exposure M = 13.375, 95% CI [11.950, 14.800]) (F(1, 30) = 7.075, η² = .191, p < .012) even though each group had the same number of years of ASL exposure.

This analysis indicates that age of ASL acquisition rather than duration of sign language exposure is a better predictor of success on this PA measure. This finding adds to the growing evidence that native language exposure provides unique benefits in a variety of linguistic domains (Mayberry, Lock, & Kazmi, 2002; Newport, 1990, 1991).

As noted in the introduction, PA, while typically used to describe awareness of sound structure in spoken languages, may be a valid construct for describing one’s sensitivity to the structural properties of a signed language. Here we have been able to demonstrate that a novel test of ASL PA, in which successful performance required participants to mentally manipulate and recombine structural properties of ASL nonsigns to form well-formed signs, was sensitive to age of ASL acquisition. An important question concerns whether this ASL PA ability affords cross-language processing advantages to other PA tests, for example, those based on English.

ASL and English PA

Deaf individuals have been shown to show sensitivity to sound-based phonological properties of English, yet the performance on such measures differs from that of hearing individuals (Hanson & Fowler, 1987). To many, the existence of sensitivity to sound characteristics in deaf individuals is surprising or at best counterintuitive. However, given the great variability in the factors and profiles that comprise deafness (i.e., age of onset, etiology of hearing loss, changes in hearing over time, difference in audiological profiles, use of assistive
listening devices, etc.), and educational and speech and language rehabilitation practices experienced by most deaf children in the USA, it is perhaps less surprising that some deaf children develop sensitivities to aspects of spoken language phonology. Nevertheless, the mechanisms by which this may occur are poorly understood. One possibility is that PA describes not a language-specific skill, but may transcend language form and language modality. In this view, PA describes a set of routines that permit metalinguistic awareness, specifically that words (and signs) have subcomponents that are independent of the holistic word-forms. If such metalinguistic processes are supra-modal, one predicts that PA in one language may permit efficient coding of a second language. This line of reasoning predicts that signers who show the robust PA for sign language may also be those who show proclivities for PA tests in other languages that they have exposure to, in this case English.

Evidence for a supra-modal ability in deaf signers is reported in a study by MacSweeny et al. (2008). MacSweeny and colleagues used fMRI technique to explore the neural correlates of phonological decision for BSL and English in deaf and hearing participants. In the BSL experiment, pairs of pictures were displayed, and participants had to decide whether the sign names for the pictures shared the same place of articulation (i.e., location). In the English task, pairs of pictures were displayed and participants had to decide whether the names for the pictured object rhymed. Deaf signers showed a similar left-lateralized fronto-parietal network during both the BSL and English rhyming conditions. Based on these findings, MacSweeny et al. (2008) argued that such a network supports a supra-modal mode of phonological processing.

In the present study, we examined the relationship between the ASL PA test and a test of English PA. We developed an “odd man out” test of English rhyming, which required participants to view three pictures of common objects and determine which picture depicted an object whose name differed from the remaining two. We choose to use a test of English rhyming as there is an established literature on rhyming abilities in deaf participants and it could be conducted without the need for orthographic or aural processing of stimulus materials. We compared a subset of our participant pool on these two tasks.

Methods

A picture-based rhyming task was developed with 21 test trials. For each trial, three photographs of common objects were presented, two of which had pictures whose name rhymed and a third foil whose name differed in the sound characteristics from the other two (see Figure 3). Stimuli were selected based on the following criteria: (a) The numbers of letters, (b) syllables in each name were matched to each other within a set. The numbers of letters in the name of the objects were matched +/− one letter, (c) each image within a set had a name that was spelled unlike the names of other images in the set, that is they were orthographically opaque with respect to phonological form, and (d) each set contained two images with names that rhymed and one image with a name that did not rhyme with the other two. To insure that all participants used the name intended for our pictures, dashes appeared beneath the images to indicate the number of letters in the English name of the object, and for each picture we indicated the first letter of each intended picture name. An example image might be a picture of a door accompanied by the word-stub the “d__ __ __.”

Online testing used randomized sets with randomized image order within the sets. Participants responded by clicking a button below the image and submitting their choice. Participants were instructed to view the images and choose the image with an English name that sounds different from the English names of the other two images. Participants were also informed that the first letter of each image’s English name would be provided and that blanks would follow the letter to show how many letters were in the name. Participants were asked to give their best answer for each set of pictures and were allowed to take as much time as needed to complete the task.

Participants

Thirty-five deaf signers took the English rhyming test; all had participated in the ASL PA test and had valid responses on the PA measures (as described above).
Thirteen participants were native signers, 13 were early signers, and 9 late signers.

Results

A one-way ANOVA was used to compute group differences. The analysis revealed a main effect of Group ($F(2, 32) = 5.573$, $\eta^2 = .25$, $p < .0084$). Late signers were most accurate on this rhyme test ($M = 92.6$, 95% CI [81.86, 103.24]), followed by early signers ($M = 77.1$, 95% CI [62.08, 92.22]) and native signer performing the poorest ($M = 62.6$, 95% CI [50.53, 74.70]). Planned comparisons showed that late signers were significantly more accurate on the rhyming test than native signers (Late−Native, $= 29.94\%$, $p < .006$). Late signers did not differ significantly from early signers (Late−Early, $M = 15.40\%$, $p = .217$). Nor did native signers differ from early signers (Native−Early, $M = 14.53\%$, $p = .19$).

To further explore the relationship between performance on ASL PA and the English Rhyming task, we present a scatter plot of data in Figure 4. For the sake of clarity we have collapsed early and nonnatives signers into a single group. Linear regression trend lines show a moderate to strong relationship between performance on the ASL PA test and the English Rhyming test ($R^2 = .66$) for native signers. In contrast, nonnative signers show little relationship ($R^2 = .006$). However we must be cautious about these results given the number of participants tested and the number of nonnatives signers who performed at ceiling on the English measure.

Discussion

The analysis reveals that overall, deaf participants were able to perform the English rhyming test, though variation in performance is clearly evident. Late learners of ASL performed significantly better than native signers on this test. Signers who learn ASL later in life are more likely to rely on the spoken language used in the home to communicate with parents and friends. These individuals may have more opportunities and pressure to develop spoken English skills, which may contribute to the performance on the English rhyming test. This skill may account for the better performance of late signers and the intermediate performance of early signers relative to native signers. In addition, as noted in Table 1, late signers show evidence of less severe hearing loss than either native or early signer, this difference may also contribute to more accessible phonological knowledge of English. Native ASL signers, who, from infancy, have a useful and effective means

Figure 3 Stimulus items from the English phonological awareness test.
of communication, may not be pressured to develop commensurate spoken English language skills, resulting in poorer performance on this metalinguistic task of English phonology.

In a comparison across PA tasks, we observed a strong positive correlation for native signing participants. Native signers who performed best on our ASL PA test were also more adept at the English rhyming task. This relationship did not hold for either early or late signing participants. There are several important points to consider in evaluating this finding.

The lack of a relationship may be driven, in part, by ceiling effects especially for the late learners (and to a lesser extent, early learners) who generally performed quite well on the English rhyming test. Second, for this subset of native signers, the performance on the ASL PA test well distributed, that is, these participants were not at ceiling on either PA test. This latter observation underscores a more general, but important point–native experience alone is not an assurance of competence in PA. For example, in the adult population of hearing monolingual users of English there remains variation on tests of PA (see, e.g., Castles, Holmes, Neath, & Kinoshita, 2003). The graded performance of the native signers may be a reflection of such variation.

An alternative explanation may come from consideration of language transfer effects in bilingualism. There is a rich developmental literature that indicates evidence for cross-language transfer of PA in bilingual children. Such studies indicate that stimulation of PA of bilingual children in either of their languages is likely to transfer to the other language. Such effects are often considered consistent with hypothesis of language interdependence (see Cummins, 1981, Verhoeven, 1994). These effects are reported in structurally similar language such as English and Spanish (Dickinson, McCabe, Clark-Chiarelli, & Wolf, 2004; Durgunoglu, Nagy, & Hancin-Bhatt, 1993), as well as more structurally divergent languages including Turkish and Dutch (Verhoeven, 2007), and Chinese and English (Chen, Xu, Nguyen, Hong & Wang, 2010). Studies from adult language learners also report evidence of cross-language transfer of PA (Abu-Rabia, 2001). Under this account the level of PA demonstrated in native deaf users L1 (ASL) would mirror their performance in L2 (English). This relationship provides support for the contention that PA, as measured by these tests, may be a metalinguistic skill that transcends language modality. A full accounting of the interpretation of this relationship must remain tentative especially in light of the small numbers of participants in this analysis.

Figure 4 Scatter plot of participants performance on the American Sign Language and English phonological awareness tests.
General Discussion

The study of PA in deaf individuals has been dominated by studies that have explored the relationship between metalinguistic skills of spoken language and reading achievement. In contrast, the present study sought to explore the construct of PA as it applies to a natural signed language, ASL. We developed a multiple-choice measure that required participants to examine two phonotactically possible pseudosigns and to isolate and recombine the articulatory parameters of these pseudosigns in such a way as to create a possible sign. We believe this ability requires a metalinguistic awareness of the structural components of ASL signs. We observed that native deaf signers were more accurate on this task than either early-exposed signers (those with sign exposure prior to eight years of age) or late learners of signed language (those with sign exposure after eight years of age). Moreover, we showed that the better performance of native deaf signers was present even after controlling for the number of years of sign language experience. We then examined performance of a subset of our participants on an English test of PA. Late signers were significantly more accurate than native signers while early signers performance fell in between that of late signers and native signers. We suggested that competency in the use of spoken English and differences in the degree of hearing loss may contribute to this pattern of results. Comparing across ASL PA and English PA we observed that for native signers, there was a moderately strong correlation between ASL PA and a picture-based test of English rhyming. This relationship was not observed for early or late signers, however methodological factors such as number of participants may have limited our ability to detect such relationships. We entertained the possibility that this relationship reflects effects of language transfer and language interdependence in ASL/English bilinguals.

Several important findings emerge from this research. First, it appears that an off-line measure can be developed to assess PA for a naturally occurring signed language. The linguistic properties manipulated in our test items are based upon independently motivated models of ASL phonological structure that argue that formational parameters of sign formation include separate specifications for handshape, location, movement, and orientation. Our results further indicate that such a measure is able to discriminate signers based upon language background and is particularly sensitive to native language experience. However, it should be noted that nonnative signers did not “fail” this test, but were merely less accurate than native signers. Indeed variation among native signers on this test was evident reinforcing the point that native language competence does not insure metalinguistic PA. Thus, while the native language acquisition of ASL may afford some facility in development of PA as measured by this current instrument it is not a necessary requirement for developing metalinguistic skills in ASL.

Our findings also show a relationship between PA in ASL and PA in English in native signers. This observation is consistent with a supra-modal account of the processes underlying PA in deaf signers. In this view, PA may reflect a general metalinguistic skill that can be deployed across different languages and language modalities. Our findings are consistent with recent brain imaging data in deaf signers that indicates a left-lateralized fronto-parietal network involved in the manipulation of phonological elements in English and BSL (MacSweeney et al., 2008).

Taken together, the present findings may help us understand why native competence in ASL is a good predictor of success in English reading (Chamberlain & Mayberry, 2000, 2008; Goldin-Meadow & Mayberry, 2001; Hoffmeister, 2000). In our view, native ASL experience may provide affordances in metalinguistic abilities that may be marshaled to aid in the mapping of print to meaning in the cases of deaf readers. Further work is required to fully establish the causal links between PA in ASL and reading in English, in the deaf population, but the present findings provide a promising line of investigation.

Notes

1. This is an English translation of the type of ASL sentence used in Gutierrez et al. (2012).
2. Asking deaf participants to self-report their age of exposure to ASL can lead to a variety of responses. For example, several participants reported learning SEE or PSE in elementary school programs, but ASL in middle school. Some nonnative respondents indicate that it was not until they took formal classes in ASL, that they were exposed to ASL, often indicating that their own signing prior to this time was Pidgin Signed English (PSE) with their deaf classmates. In cases where age of exposure...
was unclear or questionable (six cases) we considered school placement (residential or mainstreamed), family composition, and reported use of language with parent, siblings, and friends in our determination.

3. Many nonnative deaf signers are exposed to signed forms of communication other than ASL, for example, Pulgin Signed English (PSE) or SEE, etc. We recognize that these other signed systems have compositional structure and make use of the same parameters we have manipulated in our experiment. We would expect competencies in these non–ASL communicative strategies to also contribute to the types of experiences needed to develop ASL PA.

4. Independent regression plots for early and late signers showed no consistent relationships between performance on the English rhyme task and performance on the ASL PA task. Regression coefficients for the early signers, $R^2 = .039$, for late signers, $R^2 = .063$.

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**Conflicts of Interest**

No conflicts of interest were reported.

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