Phonological substitution errors in L2 ASL sentence processing by hearing M2L2 learners

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Abstract
In the present study we aimed to investigate phonological substitution errors made by hearing second language (M2L2) learners of American Sign Language (ASL) during a sentence translation task. Learners saw sentences in ASL that were signed by either a native signer or a M2L2 learner. Learners were to simply translate the sentence from ASL to English. Learners’ responses were analysed for lexical translation errors that were caused by phonological parameter substitutions. Unlike previous related studies, tracking phonological substitution errors during sentence translation allows for the characterization of uncontrolled and naturalistic perception errors. Results indicated that learners made mostly movement errors followed by handshape and location errors. Learners made more movement errors for sentences signed by the M2L2 learner relative to those by the native signer. Additionally, high proficiency learners made more handshape errors than low proficiency learners. Taken together, this pattern of results suggests that late M2L2 learners are poor at perceiving the movement parameter and M2L2 production variability of the movement parameter negatively contributes to perception.

Keywords
American Sign Language, bimodal bilingualism, phonological errors, second language, sign perception

1 Introduction
Second language learners often have difficulty in perceiving and producing phonological contrasts in their second language (Best and Tyler, 2007; Flege, 1995; MacKain et al., 1981). These findings are often reported for unimodal L2 learners who are acquiring
another spoken second language. A growing body of research, however, has begun to explore phonological perception and production of bimodal (M2; second modality) L2 learners of sign languages (see, amongst others, Bochner et al., 2011; Morford et al., 2008; Morford and Carlson, 2011). The aim of the present study was to explore the phonological errors that M2L2 learners of American Sign Language (ASL) make during ASL sentence processing. Additionally, we investigated whether phonological substitution errors differed across native and M2L2 interlocutors.

II Background

American Sign Language is the primary language of deaf/Deaf³ and hard-of-hearing individuals in the USA. ASL is a natural language with all of the same linguistic characteristics of spoken language (e.g. phonology, morphology, syntax, semantics; Sandler and Lillo-Martin, 2006). ASL phonology includes at least three sublexical features: handshape, movement, and location (for the sublexical characteristics of the sign cheese,² see Figure 1; Brentari, 1998; Liddell and Johnson, 1989; Sandler, 1989). Handshape is the configuration and the selected fingers and joints of the articulating hands during sign production. Movement is the directionality and path features of the hands during sign production. Location is the place on the body where the sign is being articulated. Another proposed sublexical feature of sign languages is orientation (also included in Figure 1). Orientation is the palm position in a 3D coordinate space of articulation used for sign production. Some phonologists argue that orientation is a separate sublexical feature (Brentari, 1998) while others propose that it is included in the feature geometry of the hand configuration (Sandler, 1989). Due to the lack of consensus on the orientation feature and the fact that some previous studies have also excluded orientation (e.g. Morford and Carlson, 2011), only handshape, movement, and location will be analysed in this study.

Sign language perception and the intelligibility thereof can be influenced by the phonological characteristics of the signs themselves. The accuracy and timing of perception for each sublexical feature during sign processing is different, which can also be modulated by language experience. One of the earliest and most accurately acquired sublexical features in sign language is location (Marentette and Mayberry, 2000; Meier, 2000). M2L2 learners often focus on the subtle sub-phonemic features of the handshape parameter, which often leads to higher errors in a handshape monitoring task relative to native signers (Chen Pichler, 2011; Grosvald et al., 2012; Morford and Carlson, 2011). Movement is one of the more difficult sublexical features to perceive for M2L2 learners such that the highest error rates in perception are seen for sentences that contain signs contrasting in movement features (Bochner et al., 2011). Moreover, nonsigners and non-native signers have difficulty acquiring and discriminating signs based on movement features due to their highly complex and less perceptually salient characteristics (Brentari, 1998). Although there is limited research on perception of these phonological parameters in hearing M2L2 learners and little consensus on the order of acquisition, one previous study has looked into perception of these phonological parameters to suggest a tentative hierarchy of perceptual difficulty (Bochner et al., 2011).

A previous same–different task investigated phonological parameter discrimination in a sentence-matching paradigm with embedded minimal pairs contrasting in handshape,
orientation, location, movement, and complex morphology (Bochner et al., 2011). The authors demonstrated increased errors in same–different responses for sentences containing minimal pairs (i.e. different trials) compared to sentences that did not (i.e. same trials). Moreover, there were more errors in same–different judgments for sentences that contained minimal pairs that differed by movement than handshape or location.

Late learners’ perceptual confusion of phonological units may lead to greater phonological errors. Mayberry and colleagues found similar phonological errors for late learners, which suggests that difficulty processing the phonological structure of signs leads to greater substitution errors (Mayberry, 2007; Mayberry and Eichen, 1991). The primary aim for the present study was to investigate whether there were uncontrolled and naturalistic phonological errors while viewing ASL sentences. Based on the aforementioned studies, it was hypothesized in the present study that learners would make phonological substitution errors during signed sentence processing and that each phonological parameter would have different prevalence rates. Location errors were posited to be rare due to their perceptual salience. Handshape and movement errors were expected to be relatively high due to their proposed difficulty. These effects, however, have only been seen in L2 perception of native signer production; it is less known how L2 perception is modulated by L2 input.

Another primary aim of the present study was to investigate whether phonological errors are modulated by the interlocutor’s proficiency. It has also been shown that the native status of the interlocutor influences the listener’s perception (Bent and Bradlow, 2003; Xie and Fowler, 2013). However, second language learners often have gains in intelligibility compared to native speakers when listening to other nonnative talkers. This phenomenon is called the ‘interlanguage speech intelligibility benefit’ (ISIB; Bent and Bradlow, 2003). That is, L2 learners have equal or greater word recognition for words produced by nonnative speakers than native speakers of a given target language. This same phenomenon may arise for L2 learners of sign language when processing native and nonnative sign production. L2 learners in fact produce nonnative cues when signing (Cull, 2014; McDermid, 2014; Rosen, 2004). Nonnative cues (i.e. handshape and movement distortions, location variability, etc.) that surface due to acquiring a new sensorimotor system for language production may connect these nonnative signers in a similar way relative to hearing nonnative speakers. These nonnative cues, or changes to signing production, might arise out of an L2 dialect often attributed to nonnative signers (McDermid, 2014).
Evidence for an L2 dialect comes from research examining the sign production of M2L2 signers. Rosen (2004) has shown that M2L2 signers often make multiple substitutions, deletions, and phonological changes to the sublexical features in their production. Nonnative (L2) sign production is often characterized with greater movement variability relative to native signers, as indexed by lower spatiotemporal stability for sign movements (Hilger et al., 2015). Mirus and colleagues (2001) have argued that even when a nonnative signer produces all of the sublexical features correctly they can still appear nonnative by native signers. Nonnative signers may articulate signs using different articulating joints relative to native signers (Mirus et al., 2001). For example, nonnative signers might articulate the sign war using the shoulders compared to native signers who use the elbows. This alternation is grammatically correct but inappropriate for many sign registers, which sets nonnative signers apart from native signers (Mirus et al., 2001). With emerging support for an L2 dialect, the salient features produced by M2L2 could be reinforced through experience with their own productions and could result in differences in perception across signers. That is, M2L2 learners of sign language produce nonnative-like sign production and thus may modulate the errors that are perceived by M2L2 learners. As such, we wanted to examine how the native status of the interlocutor influence phonological errors made by M2L2 learners during ASL sentential processing.

An ASL-to-English sentence translation task was constructed to probe the distribution of phonological errors while viewing ASL sentences. Many of the previously mentioned studies have, in one way or another, forced learners to make phonological substitution errors during task performance. However, it is unclear whether learners make phonological errors while processing ASL sentences. In the ASL-to-English translation task learners are presented with a plausible or implausible sentence in ASL. Learners made a plausibility judgment and subsequently translated the ASL sentence into English. This task is most advantageous in probing the distribution of naturalistic phonological errors because learners must process an ASL sentence and recall that sentence in a manner that is not impacted by L2 ASL production proficiency. Although this task does not allow for comprehension to be directly probed, or for the locus of phonological errors (i.e. perception/encoding, maintenance, or recall) to be determined, the task does provide a unique way to probe naturalistic phonological errors.

Given the translation task, the present study manipulated phonological similarity in order to increase the number of phonological errors. Previous studies in native sentence processing in English have shown that sentences are encoded into short-term memory and are easily recalled using surface representations (Potter and Lombardi, 1990). Potter and Lombardi also showed that these surface representations are not pristine and are susceptible to errors based on similarity in meaning. Sentences can also be encoded with their phonological information, especially when presented auditorily (Baddeley, 1992; Engelkamp and Rummer, 1999). As such, phonological similarity in sentence processing can increase the number of phonological errors made due to perceptual confusion during sentence recall. Poor phonological encoding and high rates of phonological errors have been seen in ASL sentence recall as well. Native signers are often unable to recognize phonological mismatches (Hanson and Bellugi, 1982), and nonnative signers make many phonological errors in sentence recall (Mayberry and Fischer, 1989).
Given that phonological similarity may increase the likelihood of phonological errors and the translation task also requires M2L2 learners to activate their L1 (English) during their processing of ASL sentences, we were tangentially interested in the effect of L1 and L2 phonological similarity. Previous studies have shown that both native bimodal bilinguals and late nonnative signers activate both their spoken language (e.g. English) and their sign language (e.g. ASL) during language processing in a number of tasks (Shook and Marian, 2012; Van Hell et al., 2009; Williams and Newman, 2015). In fact, Williams and Newman (2015) have demonstrated that not only are lexical items co-activated in both languages, but also their phonological characteristics. Therefore, co-activation of lexical items in English and their phonological characteristics may influence sign processing. So, if M2L2 learners activate English during L2 processing, especially when required during a translation task, then phonological similarity in English should negatively impact translation relative to control sentences (Baddeley, 1992).

By comparing English phonologically related sentences to neutral control sentences, we can determine whether L1 phonological information intrudes in sentence translation and recall, regardless of the divergence in phonological representations across spoken and sign languages. M2L2 learners may also show reduced errors to sentences that are phonologically related in English relative to sentences that contain phonologically related ASL signs since their native proficiency should be better able to resolve English phonological similarity in working memory (Ardila, 2003). Learners are expected to have decreased accuracy for sentences containing ASL signs that share similar phonological features (i.e. handshape, movement, location) because phonological relatedness decreases overall sign recall for native signers (Wilson and Emmorey, 1997) and may be more perceptually confusing and therefore impacts accurate encoding. It is especially likely that learners will have significant deficits in ASL-phonologically related sentences because learners have poor phonological perception wherein they make greater phonological substitutions and deletions (Mayberry and Fischer, 1989; Rosen, 2004). Therefore, by comparing ASL phonologically related sentences to neutral control sentences, we are able to demonstrate that the phonological representations are highly susceptible to errors. Furthermore, the comparison of ASL and English phonologically related sentences to one another provides insight into how language proficiency modulates these effects. Given the low likelihood of phonological errors in naturalistic sentence recall-translation, by requiring participants to process phonologically related sentences the likelihood of phonological substitution error increases. Therefore, in the present study we test how phonological substitutions are modulated by phonological relatedness in their L1 and L2. However, the present study does not attempt to identify the locus of the effects of phonological similarity: whether the phonological similarity (for either ASL or English) is due to perceptual confusion, encoding and maintenance deficits, or errors in recall.

The current study investigates intelligibility effects of native versus M2L2 signer status in the perception of ASL by M2L2 learners. The primarily aim of the current study was to answer the following questions:

1. Given that previous studies have shown that there may be a general hierarchy of difficulty in parameter identification in M2L2 learners using various techniques, do M2L2 learner’s phonological errors in sentence processing replicate previous
findings such that there will be more movement errors than handshape errors with very few location errors in a sentence translation task?

2. Given that greater production variability in the movement parameter has been documented in M2L2 learners, are there more movement errors for sentences signed by a M2L2 learner relative to those signed by a native signer?

3. Given that proficiency often modulates intelligibility benefits from other learners as well as reduces phonological errors in learners, are there reductions in specific phonological errors with increased proficiency?

4. Given that the task requires co-activation of English and phonological similarity often causes deficits in sentence recall, how does phonological similarity in English or ASL influence sentence perception and phonological error rates?

III Method

1 Participants

Data were collected from 21 participants (5 male, 16 female). The participants ranged from 18 to 23 years old ($M = 20.90, SD = 1.22$). There were 19 right-handed participants. The participants were students recruited from Intermediate I and II (3rd and 4th semesters, respectively) American Sign Language (ASL) courses at Indiana University, USA. All participants were native English speakers with no history of neurological, speech, language, or hearing disorders. Three participants reported experience with Spanish and one with Vietnamese; no other second languages were reported. On average, the participants reported to have been exposed to ASL for 3.37 years (range = 1 to 7). All participants gave written informed consent approved by the Indiana University Institutional Review Board.

2 ASL proficiency

Participants rated their proficiency in ASL, English, and any other languages studied on a scale from 1 to 7 (1 = ‘Almost None’, 2 = ‘Very Poor’, 3 = ‘Fair’, 4 = ‘Functional’, 5 = ‘Good’, 6 = ‘Very Good’, 7 = ‘Like Native’). The participants’ ASL scores ranged from 3 to 7 ($M = 4.71, SD = 0.98$). All participants rated their English abilities as a 7. The three participants that noted Spanish as another language reported scores of 2; the student with experience with Vietnamese reported a 4.

ASL ability was also measured using a Fingerspelling Reproduction Task (FRT), developed by the Visual Language and Visual Learning Center at Gallaudet University, USA (Morere, 2008). The FRT was used as a measure of ASL ability because there are relatively few openly accessible measures of ASL ability, and the FRT has been shown to correlate highly with ASL ability on an AX discrimination task (Williams and Newman, 2015). Additionally, self-reported fingerspelling has been shown to be correlated with ASL proficiency in native signers (Mayberry and Eichen, 1991). Participants saw a series of 70 fingerspelled words and nonwords. The fingerspelled strings ranged from 2 to 13 letters long and increased in complexity and speed over the duration of the test. Participants were instructed to reproduce the fingerspelled string. A highly proficient
nonnative signer coded the videos and counted only the videos with 100% letter report accuracy as correct. The total number of words and pseudowords correctly reproduced using fingerspelling was collected. The scores ranged from 17 to 60 ($M = 37.38$, $SD = 11.13$) out of possible 70.

A composite ASL proficiency score ($P$) was calculated using the questionnaire data and the FRT scores. The average standard score as a proportion of self-rating and correct responses on the FRT were used to determine the proficiency score:

$$P = \left(\frac{FRT}{70}\right) + \frac{\left(Self-Rating \right)}{7}$$

The proficiency scores range from 0 to 1. A composite of 0 indicates a naive signer, 0.5 roughly indicates an intermediate learner, and a 1 roughly indicates a near-native signer. Composite proficiency scores ranged from 0.36 to 0.85 ($M = 0.562$, $SD = 0.129$). The authors believe that this composite score is a representative measure of ASL ability because it takes into account self-perceived ability and performance on a standardized task using production. It should be noted, however, that the ability to decode fingerspelling is different from the ability to decode lexical signs; however, it is argued that these abilities are correlated (see Mayberry and Eichen, 1991) and, in the absence of other measures, this measure may be sufficient. Self-ratings also have been shown to correlate with measured proficiency in second languages (Bachman and Palmer, 1989; MacIntyre et al., 1997). Furthermore, the $P$ score correlated well with length of learning for the participants in the present study ($r = 0.663$, $p = 0.001$). A positive correlation with length of learning suggests that this score measures proficiency as a function of the amount of input and learning. Moreover, in a previous study, the composite score has been shown to accurately characterize proficiency using word recognition and discriminability tests (Williams and Newman, 2015). Together these data suggest that this measure for ASL proficiency adequately describes our learners.

### 3 Signers

A native signer (age = 21; male) produced all of the native sentences. A hearing M2L2 learner of ASL (age = 23; male) signed the L2 sentences. His first language was English. His second language was Spanish. His third language was ASL. He had formally taken four semesters of ASL, but did not actively sign on a daily basis, and reported as English dominant. The nonnative signer’s composite score (as assessed by the aforementioned procedures) was 0.879.

### 4 Stimuli

There were 120 signed ASL sentences. The sentences were split into three groups: ASL phonologically related (e.g. ‘I miss eating candy sometimes’), English phonologically related (e.g. ‘The cat ate the rat’), and neutral (e.g. ‘A skinny man is handsome’). The
majority of the content words (approximately 75%) within an ASL phonologically related sentence shared similar phonological parameters (i.e. randomly and equally distributed across handshape, location, movement). For example, in the sentence, ‘I miss eating candy sometimes’, the signs \textit{\textit{ix}pro.1p} (‘I’), \textit{MISS}, \textit{CANDY}, and \textit{SOMETIMES} share the same handshape. Additionally, the signs \textit{MISS} and \textit{EAT} (‘eating’) share the same location at the chin. The English phonologically related sentences followed the same criterion: an average of 75% of the content words in the sentence must sound similar (i.e. randomly and equally distributed across onset, vowel, and coda overlap) to each other if they were spoken. The neutral sentences (i.e. control sentences) did not contain phonological overlap in either ASL or the English translation. Half of the sentences in each group were plausible (e.g. ‘The roommate wants to fix the machine’) and the other half were implausible (e.g. ‘The fish ate the horse’) in order to require participants to attend to the entire sentence (i.e. each lexical item) for meaning.

Participant’s responses were scored based on the number of keywords correctly identified. Keywords were defined as open-class content words in the English translation (e.g. \textit{cat}, \textit{ate}, \textit{rat} from the English translation of the ASL stimulus sentence ‘The cat ate the rat’). There were a range of 3–7 keywords per sentence across all conditions ($M = 5.025, SD = 1.061$) for a total of 577 keywords per participant. There were no significant differences in number of keywords across conditions [$F < 1$].

Both the native and M2L2 signers signed all of the sentences. Both of the signers were provided the stimulus list with the English sentence and an ASL gloss. They were instructed to sign them as naturally as possible. The M2L2 signer’s productions were monitored for correct lexical items and overt phonological substitution errors; however, productions were allowed to have natural phonetic variation. That is, the stimuli were matched for the lexical items in the sentences to insure consistency across signers for keyword report, but were signed in a naturalistic way by both signers. The video clips were cropped to one frame before the signer lifted his hands to produce the first sign of the sentence and one frame after his arms came to a rest at his side to indicate the post-sentence production period. The average duration of the video clips was 4820 milliseconds ($SE = 1134$ ms). An analysis of variance (ANOVA) indicated that the video lengths were not significantly different across the phonologically relatedness conditions ($F_{(2,38)} = 2.788, p > 0.05$) or plausibility ($F_{(1,19)} = 1.204, p > 0.05$); however, they were different between signers ($F_{(1,19)} = 88.620, p < 0.001, \eta^2 = 0.823$), where the L2 sentences ($M = 5325, SE = 99$) were longer than the native sentences ($M = 4317, SE = 74$). There were no interactions across the factors, $F < 1$.

5 Procedure

Participants were seated in front of a 27-inch iMac. Stimulus presentation was controlled by \textit{PsychoPy} (Pierce, 2007) software. A fixation point was presented at the beginning of each trial for 500 milliseconds before the ASL sentence played. Once the ASL sentence was presented, the participants were instructed to make a plausibility judgment as quickly as possible by pressing the ‘1’ key if the sentence was implausible and the ‘0’ key if it was plausible. The participants were not able to make plausibility judgments until the end of the sentence, which insured exposure to all of the keywords and motivated participants to
pay attention. After the plausibility judgment, participants were instructed to translate the sentence into English by typing their response on a keyboard. They were explicitly instructed to not gloss the sentence, but rather provide a translation. However, they were also instructed to report any signs that they recognized if they did not understand the sentence. Previous studies have required participants to transcribe what they have heard in the target language (Xie and Fowler, 2013; Bent and Bradlow, 2003). The ability to transcribe the stimuli in ASL is limited, as there is no official orthographic system in ASL. Therefore, participants were asked to translate the sentences into English. Furthermore, signed reproductions were also not a viable option given that the present study aimed to capture the participants’ phonological errors in signed sentence processing. Signed reproductions could have colored their processing based on their own M2L2 production variability. Participants could take as long as they needed to enter their translations. The sentences were counterbalanced for each signer and across each participant so that no participant saw both signers sign the same sentence. The dependent measures included keyword report accuracy and phonological substitution errors. The keyword report accuracy was calculated by taking the percentage of correct content words reported. Keyword responses were also analysed for phonological substitution errors. For example, if the target keyword was summer, but the participant responded dry, then the keyword would be marked as a location phonological substitution error, as summer and dry share handshape and movement features, but differ by location (see Figure 2). In other words, a response was labeled as a phonological substitution error if the sign equivalent shared two of the three parameters with the target sign (i.e. minimal pairs). Phonological substitution errors were subsequently classified as handshape, location, or movement errors based on which parameter the target sign and the response differed. Additionally, all errors were counted insofar as any given trial may contain more than one phonological substitution error. The reader should be reminded that these phonological substitution errors were derived by the English responses and not any sign productions. Correlations between proficiency and phonological substitution errors were calculated in order to measure the effect of proficiency on errors made by M2L2 learners.

IV Results

1 Keyword accuracy

A repeated measures 2 (Signer: native vs. L2) by 3 (Relatedness: ASL vs. English vs. neutral) by 2 (Plausibility: plausible vs. implausible) analysis of variance (ANOVA) was performed. The main effect of signer was not significant \[F(1,20) = 1.287, p = 0.370, \eta^2 = 0.060\]. The learners responded with similar keyword accuracy for the M2L2 signer (M = 39.1%, SE = 3.3%) and the native signer (M = 37.9%, SE = 3.0%). There was a main effect of relatedness \[F(2,40) = 26.901, p < 0.001, \eta^2 = 0.574\]. Planned ad-hoc t-tests showed that participants were less accurate with ASL phonologically related sentences (34%) than English phonologically related sentences [39%; \(t(20) = 4.859, p < 0.001\] and control sentences [42%; \(t(20) = 7.388, p < 0.001\]. English phonologically related sentences were also less accurate than control sentences \([t(20) = 2.367, p < 0.05]\). There was no effect of plausibility \([F(1,20) = 1.139, p = 0.299, \eta^2 = 0.054]\). No interactions were significant.
There were a total of 190 phonological errors reported out of a total 4575 keywords. Therefore, participants made phonological substitution errors in 4% of their responses. The remaining errors were due to other types of response errors. A repeated-measures 2 (Signer: native vs. L2) by 3 (Parameter: location vs. handshape vs. movement) by 3 (Relatedness: ASL vs. English vs. neutral) by 2 (Plausibility: plausible vs. implausible) ANOVA was performed. The main effect of signer was not significant \( F < 1 \) as the errors made for native (\( M = 46.3\% \), \( SE = 2\% \)) and L2 (\( M = 53.68\% \), \( SE = 2\% \)) sentences were comparable. Main effects of parameter \( F(2,40) = 91.37, p < 0.0001, \eta^2 = 0.820 \), relatedness \( F(2,40) = 8.452, p < 0.001, \eta^2 = 0.297 \), and plausibility \( F(2,40) = 5.088, p < 0.05, \eta^2 = 0.203 \) were significant. The main effect of parameter (see Figure 3) revealed that participants made more movement errors (63.6%) than handshape (31.6%).

**Figure 2.** A minimal pair contrast (top: SUMMER vs. DRY) that would constitute a phonological substitution error in the present study. The minimal pair is contrasted with an unrelated lexical error (bottom).

### 2 Phonological error analysis

There were a total of 190 phonological errors reported out of a total 4575 keywords. Therefore, participants made phonological substitution errors in 4% of their responses. The remaining errors were due to other types of response errors. A repeated-measures 2 (Signer: native vs. L2) by 3 (Parameter: location vs. handshape vs. movement) by 3 (Relatedness: ASL vs. English vs. neutral) by 2 (Plausibility: plausible vs. implausible) ANOVA was performed. The main effect of signer was not significant \( F < 1 \) as the errors made for native (\( M = 46.3\% \), \( SE = 2\% \)) and L2 (\( M = 53.68\% \), \( SE = 2\% \)) sentences were comparable. Main effects of parameter \( F(2,40) = 91.37, p < 0.0001, \eta^2 = 0.820 \), relatedness \( F(2,40) = 8.452, p < 0.001, \eta^2 = 0.297 \), and plausibility \( F(2,40) = 5.088, p < 0.05, \eta^2 = 0.203 \) were significant. The main effect of parameter (see Figure 3) revealed that participants made more movement errors (63.6%) than handshape (31.6%).
or location (4.8%) errors. The main effect of relatedness revealed that the words that were phonologically related in English contained the least number of errors (20.0%), whereas those that were related in ASL (41.0%) and neutral (39.0%) sentence contained relatively equal number of errors. When examining the effect of plausibility, participants made more errors for plausible sentences (56.3%) than implausible sentences (43.7%).

Additionally interactions were present such that there was a signer by parameter interaction \[F(2,40) = 3.527, p < 0.05, \eta^2 = 0.150\] and a parameter by type interaction \[F(2,80) = 6.691, p < 0.0001, \eta^2 = 0.251\]. The signer by parameter interaction (see Figure 3) revealed that sentences signed by the M2L2 learner yielded more movement errors (36.3%) than sentences by a native signer (27.4%), but did not differ for handshape (native: 17.4%; L2: 14.2%) or location (native: 1.7%; L2: 3.2%). The parameter by type interaction reveals similar percentage of errors across the relatedness for the location parameter, but for handshape and movement there was a general trend for more errors for the control sentences, followed by the ASL-related sentences and then English-related sentences.

There was a 3-way interaction with signer, parameter, and type \[F(4,80) = 4.005, p < 0.01, \eta^2 = 0.167\]. The 3-way interaction revealed that the participants made more movement errors for the L2 sentences that contained ASL-phonologically related signs and control sentences, but few of these errors were in L2 English-related sentences. No other interactions were significant.
In order to determine that these effects were simply caused by semantic errors, a post-hoc semantic error analysis was performed on the phonological errors. It was found that 30 out of the 190 phonological errors were also semantic errors. Six sign pairs were able to explain 90% of these semantic-phonological errors: doctor-nurse (23.38%), horse-rabbit (20.0%), queen-king (13.3%), boots-shoes (13.3%), yesterday-tomorrow (10.0%), and apple-onion (10.05). Somewhat surprising is that the majority of these semantic errors were also handshape errors. Nevertheless, if the phonological errors were re-analysed omitting the semantic errors, the parameter effect is preserved wherein there were more movement errors (57.9%) than handshape errors (22.6%), which were both more numerous than location errors (3.7%). The same parameter by signer interaction was also preserved. Errors that were both semantic and phonological in nature did not change the distribution of phonological errors by parameter and can be said to not change the overall effects of the study.

3 Correlation analysis
Lower proficiency participants did not make fewer phonological substitution errors than higher proficiency participants ($R^2 = 0.120$, $r = 0.347$, $p = 0.124$). Correlations between phonological substitution errors and proficiency were analysed to characterize the changes in phonological errors for each sublexical feature as the L2 lexicon expands. With increasing evidence that perception of the location feature is easy for all signers and handshape and movement are more difficult (see above hierarchy), it was hypothesized that lower proficiency learners would have greater phonological errors for handshape and movement than higher proficiency learners, but proficiency would not modulate location errors. The more proficient learners had significantly more handshape errors ($R^2 = 0.226$, $r = 0.475$, $p < 0.05$) than lower proficiency learners; however there was no correlation between proficiency, movement and location errors. No other correlations were significant.

V General discussion
The present study adds to the growing sign perception literature by providing data concerning learners’ sign perception during ASL sentence processing. Previous sign perception studies have gauged phonological substitution errors by forcing the participants to choose between sentences that contained phonologically related minimal pairs (Bochner et al., 2011; Tartter and Fischer, 1982). In this study, however, the phonological substitution errors in the perception of ASL were spontaneous and uncontrolled. There were four main findings in the present study. First, there was a general hierarchy of phonological substitution errors where there were greater movement errors relative to handshape or location. Second, there were greater movement errors in sentences signed by the M2L2 signers. Third, participants made more handshape errors with increased proficiency, but movement and location errors were not modulated by proficiency. Last, there was evidence of L1 activation with decreased errors for sentences that were underlyingly phonologically related in English. Each of these will be discussed in turn.

The movement parameter has been documented to be difficult for hearing M2L2 learners of sign language in both perception and production (Bochner et al., 2011;
Morford and Carlson, 2011). In the present study, the results indicated that approximately 4% of the keywords reported were phonological substitutions in perception. The learners mostly made movement errors (64%), followed by handshape (31%) and location (5%) errors. The pattern of phonological errors in this study provides converging evidence with previous studies that have found location to be easily perceived (and produced) relative to other features (Bochner et al., 2011; Ortega-Delgado, 2013; Marentette and Mayberry, 2000). Location has been shown to be unaffected by phonological substitution (Corina, 2000). M2L2 learners often focus on the subtle sub-phonemic features of the handshape parameter, which often leads to higher errors in a handshape monitoring task relative to native signers (Morford and Carlson, 2011). Movement is one of the more difficult sublexical features to perceive such that the highest error rates in perception are seen for sentences that contain signs contrasting in movement features (Bochner et al., 2011). As such, the present study replicates and extends these findings.

The most prevalent error type in the current study was omission errors, which accounted for 67% of all errors. It is difficult to determine the locus of these omission errors in the present study. A number of factors could have contributed to high omission rates. First, proficiency is a likely candidate insofar as these learners were not well practiced on sentence-level processing. Given that the task was a difficult translation task coupled with low proficiency sentence processing skills, these learners were likely to have missed a number of keywords. While it was expected that the majority of errors would be omission errors, the relative distribution of phonological errors (4% of all errors) is quite significant and provides important insight regarding the processing of ASL phonological processing and contributes to our understanding about the processing differences across the parameters.

It is also important to note that phonological substitution errors also contained semantic errors. More interestingly, the semantic errors were largely confined to minimal pairs that shared handshape. A potential explanation for this finding is that it may be a byproduct of the organization of the L2 learner lexicon, which may have a correlation between handshape minimal pairs and semantically related signs; however, more studies will need to be done in order to tease out this effect. Nonetheless, the distribution of phonological substitution errors was preserved after removing these semantic errors, which indicates that this distribution is robust and not dependent on other factors like semantics.

1 Interlanguage intelligibility benefit

Second language learners often have gains in intelligibility compared to native speakers when listening to other nonnative talkers (Bent and Bradlow, 2003; Xie and Fowler, 2013). That is, L2 learners have equal or greater word recognition for words produced by nonnative speakers than native speakers of a given target language. It was hypothesized that this interlanguage intelligibility benefit may arise for M2L2 learners of sign language when processing native and L2 sign sentences. In the present study, however, there was no overarching interlanguage intelligibility effect found. Bimodality divergence between ASL and English phonological systems may account for the lack of an interlanguage intelligibility benefit. For spoken languages, second language speech production and perception are systematically linked to the native language phonological system (e.g.
Nonnative listeners frequently find nonnative talkers more intelligible than native talkers because they have a shared base of phonetic and phonological knowledge about the L1 and L2 to draw upon during word recognition tasks. The modality divergence between ASL and English prevents the L1 from systematically affecting the L2 at the phonological level, which manifests in the lack of an interlanguage benefit for bimodal bilingual learners. In the context of the present study, a null effect is significant insofar as the concomitant bimodality divergence and absent interlanguage benefit suggests the interlanguage (speech) intelligibility benefit may only arise in languages within the same modality. For example, ASL-British Sign Language (BSL) learners might show an interlanguage benefit with other ASL learners of BSL due to the overlapping native and nonnative phonetic and phonological systems. The pattern of results suggests that the L1 and L2 must share the same modality for an interlanguage intelligibility benefit to arise.

On the other hand, participants made qualitatively more phonological substitution errors for sentences signed by a M2L2 learner and significantly more movement errors for the sentences produced by the M2L2 learner. This increase in movement errors in L2 perception of M2L2 production may be due to production variability by the M2L2 model, which in turn created greater confusability for an already poor ASL learner. M2L2 learners produce nonnative cues when signing and with high variability (Cull, 2014; Hilger et al., 2015; McDermid, 2014; Rosen, 2004). As such, M2L2 productions are more highly variable than native signers, especially in their use of the movement parameter. Additionally, M2L2 signers’ production of movement reliably differentiated them from native signers (Cull, 2014). Taken together, it seems as though not only do M2L2 learners have more errors in their perception of movement (e.g. Bochner et al., 2011), but also in their production of the movement parameter (e.g. Cull, 2014; McDermid, 2014; Rosen, 2004). A signer effect for only the perception of the movement parameter is especially interesting given that there were no other signer effects found in the present study. An absence of signer effects in other conditions suggests that the movement parameter itself is specifically vulnerable to signer status (at least for this M2L2 sign model). All in all, the participants in the present study increased movement errors for sentences produced by another M2L2 learner, which suggests that such production variability also additively affects L2 perception of the movement parameter. Higher error rates in perception of L2 signing does not support the predictions made by the interlanguage speech intelligibility benefit either. High L2 errors coupled with a null effect of signer in keyword accuracy would suggest that perhaps the ISIB is largely restricted to two languages of the same modality.

2 Phonological errors and proficiency

A surprising result in the current study is that the more proficient learners showed greater handshape errors than lower proficiency learners. This result may be attributed to the fact that learners often focus on the handshape phonetic feature, which causes nonnative learners to make more errors (Grosvald et al., 2012; Morford and Carlson, 2011). Another possible explanation is that higher proficiency learners have larger vocabularies, which may account for the increase in handshape errors. Larger vocabularies require
restructuring of the lexicon to accommodate newly learned lexical items. The lexicon is structured as a network with lexical neighborhoods of phonologically similar words (Luce and Pisoni, 1998). Signs have been shown to cluster in dense neighborhoods based on the handshape feature (Caselli and Cohen-Goldberg, 2014; Carreiras et al., 2008). Increased activation of phonological neighbors often results in more errors in spoken language recognition tasks (Vitevitch, 2002; Vitevitch and Luce, 1998). Increased activation of handshape neighbors might also account for increased phonological substitution errors. The spontaneous phonological error patterns in the present study provide evidence for shared activation of signs based on sublexical features in the L2 lexicon (e.g. handshape competition) and for increased sublexical activation in higher proficiency learners. Furthermore, stagnant errors in movement across proficiency levels suggest that the movement parameter is in fact one of the later acquired parameters during M2L2 acquisition.

Given the one fundamental characteristic of nonnative signing is large production variability, the observed results may happen to be a consequence of the participants’ incomplete fluency. However, given that some M2L2 learners can in fact produce sign language with native-like stability (Hilger et al., 2015), it may be the case that learners can overcome such a barrier to achieve target-like perception and production. Despite this possibility, learners and native signers both have difficulty in processing the movement parameter, which provides detailed insights into the nature of sign language acquisition. Siedlecki and Bonvillian (1993) found that deaf children were less accurate in their production of movement than other parameters and their production accuracy remained stable throughout development. Additionally, studies have shown that perception of movement is difficult for deaf adults as well as M2L2 learners (Bochner et al., 2011). Therefore, it may be argued that the acquisition of the movement parameter may hinder the ultimate attainment of greater sign language proficiency. However, this is only speculative at the moment. Nevertheless, given this hypothesized perception-production link, L2 ASL instruction may be able to target movement processing by reducing the signer production variability.

3 Cross-modal language co-activation in sentence processing

In addition to the influence of signer status and phonological parameter on sentence processing, we were interested in understanding the role of the learners’ L1 (English) in the perception of ASL. Language-specific phonological relatedness was manipulated to characterize the interactions between the first and second languages in ASL sentence processing. Additionally, the manipulation examined how interactions between the two languages might affect the intelligibility of the native and L2 signers. Participants were less accurate overall with the ASL phonologically related sentences. Furthermore, the detrimental effects of ASL relatedness did not diminish for the higher proficiency learners. Therefore, visuophonetic confusability may create interference that proficiency (i.e. mastery of phonological features of ASL) cannot overcome for those participants in this study. In fact, a previous study has shown that ASL phonological relatedness can interfere with processing even in native signers (Treiman and Hirsh-Pasek, 1983) as well as recall of a list of signs (Wilson and Emmorey, 1997). Participants were more accurate for sentences that were phonologically related in English relative to sentences that were
phonologically related in ASL. However, proficiency also did not modulate the accuracy for English-related sentences in the present study, which is likely due to comparable co-activation of the dominant L1 that was required for sentence translation.

Not only did participants have reduced phonological errors in sentences that underlyingly rhymed in English relative to sentences that rhymed in ASL, but also learners were more accurate for English phonologically related sentences than the control sentences. This is somewhat surprising given that phonological similarity in any language often produces a ‘phonological similarity decrement’ in which there are increased errors (Baddeley, 1992). However, facilitation of phonologically similar items has been seen in a similar task as the one in the present study (Copeland and Radvansky, 2001; Tehan et al., 2001). Copeland and Radvansky (2001) used rhyming words in a complex span task and found a facilitation effect of phonological similarity. Memory for rhyming words may be greater than non-rhyming words, which may reflect individual strategies of encoding only initial letters or reflect other cues during redintegration (Baddeley et al., 2003; Fallon et al., 1999; Gathercole et al., 1999; Lobley et al., 2005). Therefore, the facilitative role of English rhyming on ASL processing may be reflective of these encoding and redintegration memory processes that are established in the L1, but have not yet emerged in the L2. Another possibility for this observation could solely be perceptual. It is possible that the learners could predict the next word in the sentence based on their phonological similarity (i.e. there is only a limited set of possibilities if the words must rhyme) and a correct prediction would facilitate accuracy. However, these hypotheses are only speculative in nature at the present time. Nevertheless, it can be said that co-activation of a spoken language influences, and perhaps facilitates, sign language processing in late L2 learners of sign language.

4 Limitations

The present study was able to contribute a number of novel findings in the field of M2L2 acquisition; however, there are a few limitations. First, the translation task itself could impact the results. The translation task required participants to have adequate lexical knowledge to complete the task. If the learner had reduced lexical knowledge, then they might only make errors based on the words in their limited lexicon. However, these learners were selected from intermediate-to-advance level courses so that the participants would have an adequate vocabulary and lexical knowledge. Moreover, the words included in the stimulus sentences were also selected from their textbooks. Therefore, lexical knowledge (or lack thereof) could not completely explain the effects in the present study. It should also be noted that the poor accuracy performance by these learners is most likely indicative of task difficulty. In the present study, learners had to hold a long sentence, which was also perceptually confusing (i.e. phonologically related), in memory and then translate that sentence into English. The high memory load in addition to the phonologically confusing sentences likely contributed to the poor performance. Nevertheless, taxing memory constraints may have been able to advantageously elicited phonological errors in M2L2 learners.

Another limitation may be that the translation task could have introduced a strong influence from English on task performance. That is, learners were required to translate
ASL to English in order to report the keywords. As such, a reliance on English may have enhanced the facilitatory role of English on ASL sentence processing. Thus, any results that demonstrate the facilitatory role of English in ASL processing needs to be accepted cautiously; nevertheless, it is not unreasonable to suggest such L1 transfer effects in M2L2 processing. Additionally, it is impossible to determine the locus of the present effects. For instance, there are three possible loci of the phonological errors:

1. a perceptual error due to the learners incorrectly processing the visual input;
2. an encoding error due to the learners to correctly parsing the visual input but incorrectly mapping it onto the wrong lexical item; and
3. a maintenance or recall error due to the learners correctly encoding the lexical item, but failing to recall the correct information.

Nevertheless, we have been able to show that phonological errors arise during sentential processing and the distribution is consonant with previous perceptual studies.

Finally, another limitation of the current study is that there was only one sign model for the native and nonnative groups. Limiting sign utterances to one native and one M2L2 signer reduces confidence as to whether any signer effects were simply due to individual variation in these particular signers. Further studies will be needed to examine the effects of signer variability on L2 sign perception.

VI Conclusions

In conclusion, the present study adds to the growing sign perception literature by providing spontaneous and naturalistic phonological errors during learners’ sign perception during sentence processing in continuous signing. The results showed that there were greater movement errors relative to handshape or location for both native and L2 sentences, but there were more movement errors for L2 sentences relative to those signed by a native signer. Taken together, this pattern of results suggests that movement is one of the later acquired phonological parameters for M2L2 learners and L2 production variability of the movement parameter also impacts perception.

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Notes

1. Capitalized Deaf often refers to those individuals who were born deaf and consider themselves part of Deaf culture, including using American Sign Language, whereas the lowercase deaf often refers just to audiological status among those who are late-deafened or do not identify with the Deaf community.

2. Small lower-case letters is the convention for glossing ASL signs.

3. The data are normally distributed (Jarque–Bera test: \( p = 0.2124 \)) and had been transformed using arcsine and rau transformations in previous analyses, and the results were unchanged. Thus, it was decided to present the data as raw proportions for clarity and simplicity.

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