

**“MODALITY ADAPTATION HYPOTHESIS”: NEUROCOGNITIVE
ALTERATIONS TO NOVEL VISUOSPATIAL COMPONENTS OF SIGN
LANGUAGE DURING INITIAL ACQUISITION IN ADULTHOOD**

by

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Dissertation

Submitted to the faculty of the University Graduate School

in partial fulfillment of the requirements

for the degree

Doctor of Philosophy

in the Department of Psychological and Brain Sciences,

Indiana University

April 2017

The Dissertation Committee for Joshua Taylor Williams certifies that this is
the approved version of the following dissertation:

**“MODALITY ADAPTATION HYPOTHESIS”: NEUROCOGNITIVE
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Accepted by the Graduate Faculty, Indiana University, in partial fulfillment
of the requirements for the degree of Doctor of Philosophy.

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Acknowledgements

To my advisor, Sharlene Newman, thank you for being an amazing mentor. You let me have freedom to find myself academically and personally. You were always enthusiastic. You were always so real. Sometimes you were cynical. No matter what, you always kept me grounded. I want to thank you for all of your support. Without it, I don't know where I would be.

To my second advisor, Isabelle Darcy, thank you for adding a fresh perspective to my research. Your inquisitive nature into sign language phonology and expertise in second language learning provided me with invigorating insights into the value of sign language in second language studies.

To my other committee members, David Pisoni and Laura Murray, thank you for the long conversations we've had in your offices, ranging from the current landscape of academia to future opportunities. You have both challenged me to explore different perspectives in all aspects of my life.

Some big thanks go out to all of my Deaf collaborators around the nation, including Peter Hauser, Adam Stone, and Leah Geer. Thank you so much for teaching me the power of sign language and Deaf culture as well as sharing your amazing scientific perspective. Additionally, all of my

other sign linguists around the world, thank you for advocating for such a precious language and amazing culture. Let sign language flourish!

To the Deaf ASL Faculty at IU, thank you for keeping me on my toes and reminding me that my theoretical work has strong implications to not only hearing classroom students, but also society's perception of sign language and Deaf culture broadly. I commend your day-to-day fight for sign language equality.

Lastly, but of course not least, I would like to thank my partner, Nicholas DeGraan-Weber, for providing me the love, comfort, and support that energized me throughout graduate school. Your constant support has allowed me to make it through all of the uncertainty and the roller coaster ride of graduate school. Just as this dissertation is a memorandum of my hard work in science, I wanted you to be forever remembered herein. With love, thank you!

JOSHUA TAYLOR WILLIAMS

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April 2017

Abstract

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“MODALITY ADAPTATION HYPOTHESIS”: NEUROCOGNITIVE ALTERATIONS TO NOVEL VISUOSPATIAL COMPONENTS OF SIGN LANGUAGE DURING INITIAL ACQUISITION IN ADULTHOOD

This dissertation explored how the neurocognitive system changes when exposed to a manual-visual language, like American Sign Language. Hearing individuals' neurocognitive system is highly attuned to sequentially ordered acoustic information, which is molded by experience with their first (spoken) language and sets a foundation for learning-induced plasticity during second language (L2) acquisition. However, sign languages (SL) are visual languages that use the hands, body, and face to produce sequentially and simultaneously presented linguistic information, which are dependent on robust and dynamic visuospatial processing at all levels of linguistic analysis. Integration of multiple visuospatial cues at all levels of linguistic analysis provides affordances that likely shape the neurocognitive system. Therefore, this dissertation aimed to advance a novel hypothesis called the *Modality Adaptation Hypothesis* (MAH). The MAH posits that adult hearing L2 learners must acquire the unique aspects of their new visual language modality before amodal linguistic representations can be accurately acquired. The formulation of the MAH draws upon a myriad of evidence from a longitudinal neuroimaging study

of L2 acquisition by hearing learners, and other studies examining the role of movement in M2L2 acquisition.

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Chapter 1: Introduction

To understand language is to be able to successfully integrate information from various sensorimotor systems. For example, speech perception requires integration of visual and acoustic cues (Campbell, 2008; Sumbly & Pollack, 1954; Summerfield, 1992). Humans are constantly using and integrating various sensorimotor information for other linguistic tasks, such as processing co-speech gesture, reading, and writing. Despite the constant integration of visual and acoustic cues for spoken language comprehension, visual cues are often superfluous and only enhance perception; hearing language users can easily and reliably comprehend language without the use of vision, but often cannot accurately understand language with visual cues alone (e.g., Altieri & Huddock, 2014; Altieri, Pisoni, & Townsend, 2011). Hearing individuals' neurocognitive system is highly attuned to sequentially ordered acoustic information (Burton, Small, & Blumstein, 2000; Zatorre, Evens, Meyer, & Gjedde, 1992; Zatorre, Meyere, Gjedde, & Evens, 1996), which is molded by experience with their first (spoken) language. Although new language learning in adulthood challenges the brain to adapt to new statistical information in the language stream, new phonemic categories must be constructed, new lexical items must be incorporated into the lexicon, and new motor programs need to be learned and executed. The first language sets a foundation that supports language learning-induced plasticity during second language (L2) acquisition of another spoken language (e.g., Cummins, 1979). For instance, there are linguistic similarities, such as

common spoken phonemes across the two languages, as well as neurological similarities, wherein the neural tissues that process both languages are the same (Costa, & Sebastián-Gallés, 2014; Kroll et al., 2015; Kroll & Chiarello, 2015). Despite hearing individuals being multimodal language users, it is unclear whether the acquisition of a new language that uses another modality is supported in the same manner.

Sign languages, on the other hand, are visual languages that use the hands, body, and face to produce sequentially- and simultaneously-ordered linguistic information. Sign languages are **dependent on** robust and dynamic visuospatial **dependencies** at all levels of linguistic analysis (Emmorey, 2001; Sandler & Lillo-Martin, 2006). Not only does sign language comprehension incorporate similar visual cues as speech perception, such as mouthing and gesture, but the visuospatial aspects of sign languages can diverge greatly (Bickford & Fraychineaud, 2006; Emmorey, 2002). For instance, complex spatial dependences in the grammar require finer-grained spatial representations in memory. Moreover, lexical-semantic and morphological processing is highly dependent on the visuospatial aspects at the phonetic level. For example, the difference between the signs WORK and WORK-HARD-CONTINUOUSLY is due to movement velocity and repetition (alongside visual cues on the face), but all other phonetic features (e.g., handshape, location, orientation, and movement type) are all kept the same. Integration of

multiple visuospatial cues at all levels of linguistic analysis provide affordances that likely shape the neurocognitive system.

Differences in language modality are subserved by the respective sensory system's preferential treatment of various types of information. The visual system is attuned to vertical processing, or the processing of simultaneously layered information; the auditory system, on the other hand, is attuned to horizontal processing, or the processing of sequentially-ordered information (Geer, 2016; Green, 1971; Hirsch & Sherrick, 1961; Welch & Warren, 1986). Hearing adults have decades of experience with one language modality that prioritizes and automatizes acoustic information, and their neurocognitive system is not finely attuned to simultaneous visual encoding of linguistic information in the absence of an auditory signal. When a hearing adult starts their journey learning sign language as a second language, the disparity in the language modality between the two languages may inhibit language learning, at least initially, before they have acquired more robust and automatized visuospatial (and manuomotor) routines. As such, it hypothesized that the neuroplastic adaptations that must occur during initial acquisition are dramatically different than acquiring a new language within the same modality.

Given the robust visuospatial representations and skills inherently required for sign language processing compared to the visual information used in spoken language processing, this dissertation advances a novel hypothesis (i.e., "Modality Adaptation Hypothesis") that adult hearing L2

learners must acquire the unique aspects of their new visual language modality before they can accurately acquire amodal linguistic representations. The formulation of the Modality Adaptation Hypothesis (MAH) comes from a myriad of evidence, both extant and novel, that argues visual affordances of sign languages shape behavior, cognition, and the brain.

In order to support this hypothesis, the following arguments will be made drawing on novel experimentation as well as the extant literature:

1. Neural tissues related to modality-specific (e.g., visuospatial, hand) processing are more active during initial sign language acquisition than regions involved in amodal linguistic processing. Furthermore, a switch from modality-dependent to modality-independent regions will occur with increased sign language experience (Chapter 2).
2. Poor learning outcomes are dependent on deficits in modality-specific processing, such as visuospatial processing, visual phonetic segmentation, hand and biological motion processing (Chapter 3).
3. Sign language and fingerspelling acquisition follows patterns of modality-specific perceptual features, such as visual sonority, handshape markedness, and movement features (Chapters 4 and 5).

As such, it will be argued that the affordances of the visual language not only induce modality-specific neurocognitive plasticity in initial sign language, but said plasticity is the hallmark predictor of successful language outcomes. In other words, it will be argued that the learner's ability to acquire these new visuospatial skills is proportional to their L2 sign fluency and their ultimate success in acquiring sign language as a second language.

It is important to keep in mind, however, that this hypothesis does not suggest that sign language acquisition is solely dependent on visuospatial neurocognitive plasticity. Rather, the dissertation will provide evidence that first language skills (e.g., phonetic abilities, vocabulary knowledge, etc.) can be bootstrapped during acquisition. The use of the first language further supports the argument that the divergence between language modalities affords learners the ability to capitalize on the use of subvocal speech, mouthing, and other skills. In other words, if learning a sign language did not require adaptation to the visual aspects of the language, then they would need to rely on their first language less; however, in support of the MAH, this dissertation will argue that overcoming the difficulties that are concomitant with acquisition of visual languages necessitate reliance on L1 skills; thus, during the adaptation period, their L1 is largely important. Not only does this finding support the MAH, but also provides novel evidence that, despite disparate language modalities, L1 skills are transferable between languages.

The formulation of this hypothesis is significant in many ways. First, this dissertation explores how language modality affects the behavioral and neurocognitive mechanisms that underlie second language acquisition. Much of the theory of second language acquisition is reliant on the study of spoken languages. As such, it is unclear whether these specific theories are generalizable to sign language acquisition as second language. There is value in being able to distinguish between modality-independent theories of second language acquisition from those that are specific to either spoken or sign languages. As such, a more comprehensive view of language acquisition can be delineated.

Investigation of the MAH for sign language acquisition can inform theories of neuroplasticity. It is argued that the ability to adapt, or the degree of neuroplasticity, is the mechanism that underlies initial acquisition of a sign language as a second language. By quantifying the neurocognitive changes over initial acquisition, we are able to similarly quantify the extent to which neuroplasticity is essential to language learning. As a result, the hypothesis constructs a significant framework for future neuroscientific research on neuroplasticity and language learning.

More importantly, this hypothesis can inform neurocognitive universals that underlie all learning. Similar to the first point, if comparable changes are seen in this learner population in terms of neurocognitive adaptation as has been reported for unimodal learners, then we can start to piece together a comprehensive view of how second languages are

learned. Furthermore, modality-dependent mechanisms shed light on the interaction between sensorimotor systems and general cognitive learning, which can bolster theories of embodied language processing and cognition.

Lastly, this hypothesis sets a foundation for translational work to fulfill a pedagogical need. Given that this hypothesis posits that initial acquisition is dependent upon visuospatial adaptation, then training programs and curricula can be constructed to address this domain before relying on more complex, supramodal linguistic skills. These programs can then be implemented in foreign language and interpreting programs across the world. In turn, improved language outcomes, especially in interpreting programs, would have large impacts on the quality of life for Deaf citizens who rely on superior interpreting services.

The dissertation will be split into chapters that contain already published articles that contribute to MAH. As such, each chapter will include a review of the extant literature regarding the given topic, the experiment, and discussion. A final chapter (Chapter 6) will be included to bring the entire argumentation together and flesh out the MAH.

Chapter 2: Longitudinal Evidence

This chapter has been previously published, but the formatting has been slightly modified for the purposes of this dissertation:

Williams, J.T., Darcy, I., Newman, S.D. (2016). Modality-specific processing precedes amodal linguistic processing during L2 sign language acquisition: a longitudinal study. *Cortex*, 75, 56-67. doi: 10.1016/j.cortex.2015.11.015

Introduction

The neurobiology of bilingual language processing has turned to understand the neurobiology of language that includes the study of sign languages (Emmorey, Giezen, & Gollan, 2015; Emmorey & McCullough, 2009). The study of the bimodal bilingual (i.e., bilinguals who use both a sign and spoken language) brain has been relatively sparse and has restricted itself largely to native bimodal bilinguals, or hearing individuals born into deaf signing families. However, many more adults are beginning to learn sign language in high school and college. As such, it is important to also study a group of late learning hearing adults during the acquisition of a signed second language (L2). More importantly, unlike a child who grew up with both languages simultaneously, hearing late learners have an established linguistic system that directly processes auditory-oral languages. Late learners must subsequently acquire a new language modality. The aim of the present study was to investigate how the brain is transformed by the acquisition of a language that uses a different sensorimotor modality. By using a longitudinal design, we can characterize the effect of modality on the acquisition of a second language. To our knowledge, this is the first longitudinal study of L2 sign language acquisition.

The study of bimodal bilinguals is important because there is growing behavioral evidence suggesting that both spoken and sign languages are co-activated during sign language comprehension (Geizen

& Emmorey, 2015; Shook & Marian, 2012; Williams & Newman, 2015), despite neurobiological evidence of distinct patterns of activation for sign and spoken language processing across monolingual populations (Corina, Lawyer, & Cates, 2013; Emmorey, Giezen, & Gollan, 2014; Emmorey, McCullough, Mehta, & Grabowski, 2014). Of interest to the present study is how the bimodal bilingual brain processes sign language. Bimodal bilinguals show greater activation in the bilateral parietal cortex and bilateral occipitotemporal cortex during sign comprehension (Emmorey et al., 2014; Söderfeldt et al., 1997). These areas are thought to be unique to the processing of sign languages, and have been activated by spatial classifiers and verbs in American Sign Language (ASL) in addition to other demanding visual processing tasks. Nevertheless, other studies have shown strikingly similar patterns of activation for signed and spoken words for native signers and speakers (Leonard et al., 2012; MacSweeney et al., 2002, 2006, 2008; Petitto et al., 2000). However, it is unclear whether such findings are a consequence of the native bimodal bilingual experience, and if not, what the time course is for developing such activation patterns in late learners. It is unknown whether such convergence of modality-independent neural mechanisms is present after short-term initial input of a sign language (see Schelegel, Rudelson, & Peter, 2012 for an example for unimodal bilinguals).

A functional change in brain processing has been seen for L2 learners after relatively little exposure to a second language. McLaughlin

and colleagues (McLaughlin, Osterhout, & Kim, 2004) have shown that L2 learners rapidly acquire lexico-semantic processing in the L2 after only 14 hours of instruction. L2 learners of French were given a lexical decision task on semantically primed French pairs. ERPs were recorded during the lexical decision to characterize the presence (or absence) of an N400, an index of lexico-semantic processing. L2 learners indeed had N400 effects after only 14 hours of instruction despite not showing behavioral sensitivity to word-nonword distinctions in French. Furthermore, learners started to approximate native-like ERPs after only 60 hours of instruction (McLaughlin, Osterhout, & Kim, 2004; Osterhout, McLaughlin, Pitkanen, Frenck-Mestre, & Molinaro, 2006). These neuroelectrophysiological studies indicate that L2 learners can show rapid functional changes in neural processing of a second language. However, it is less known if such results generalize to bimodal bilinguals.

Another area that has garnered much attention in bilingual brain research is that of language control. Many studies have reported greater activation for language control regions, such as the left caudate and anterior cingulate gyrus, during bilingual language processing (Abutalebi & Green, 2008; Green & Abutalebi, 2013). This effect is often attributed to the need for unimodal bilinguals to control two languages within the same modality (Green, 1998). However, recent behavioral data has not been able to show a bilingual advantage for bimodal bilinguals. This lack of a bilingual advantage for bimodal bilinguals is thought to be due to do the

languages utilizing two different sensorimotor systems and therefore eliminating the necessity to compete during production – individuals can speak and sign simultaneously (Emmorey, Luk, Pyers, & Bialystok, 2008). As such, it has been hypothesized that bimodal bilinguals may not require greater cognitive control when processing language. However, a recent study has found contrasting neurobiological evidence, showing increased grey matter volume in the left caudate head for bimodal bilinguals (Zou et al., 2012). Nevertheless, it is still largely unknown whether bimodal bilinguals require cognitive control while processing sign language. Because beginning (or low proficiency) bilinguals often require much more language control (Abutalebi, 2008), the present study is situated well to investigate whether there is activation in regions known to be involved in language control during the processing of ASL.

As indicated above, the current study has two over-arching aims. One aim was to characterize the processing of ASL signs in hearing late L2 learners of ASL. Specifically, whether or not sign language processing moves from a general modality-specific stage of processing (e.g., visual, spatial, and motoric) to a more modality-independent linguistic processing stage (i.e., phonological and lexical) was investigated. That is, given that late L2 learners of ASL have an established spoken language linguistic system, it may be the case that the acquisition of a sign language requires the acquisition of modality-specific neural mechanisms as a prerequisite, which may be different from native bimodal bilinguals whose language

systems were acquired simultaneously. Additionally, the present study was interested in the time course of these neural changes due to learning a sign language. Given that previous studies have shown rapid neural changes related to L2 instruction (McLaughlin et al., 2004) and similar lexico-semantic processing early in L2 sign language acquisition (Leonard et al., 2013), we are also interested in whether and to what extent L2 acquisition is modality-independent. The second aim was to determine whether language control is evident in learning a second language in a different modality. Specifically, we examined the presence of activation in the left caudate and anterior cingulate regions during ASL processing, and when such activation first started to appear over time.

These questions motivated a longitudinal design in which naïve L2 ASL learners were followed starting before significant sign language exposure through 10 months of learning (two academic semesters). They were assessed three times: before exposure, after one semester of exposure and at the end of a second semester. The few longitudinal L2 neuroimaging studies that have been performed have only included two time points and have studied unimodal bilinguals (e.g., Stein et al., 2009). To our knowledge, this is the first longitudinal investigation of late bimodal language learners. Consequently, novel insight into the functional brain changes that occur during the acquisition of a language with a different sensorimotor modality from one's native language can be highlighted.

Following the aims outlined above, the present study makes the following predictions across the three time points:

1. If hearing late learners of sign language require modality-specific neural mechanisms for sign language processing, then there will be mostly activation in visual (e.g., calcarine sulcus, right inferior temporal sulcus) and motor (e.g., supplemental motor area) regions in response to ASL signs before any exposure to sign language (i.e., T0).

2. If hearing late learners of sign language acquire prerequisite modality-specific processing at early stages of acquisition and linguistic processing follows, then there will be greater phonological (e.g., left superior marginal gyrus) and lexico-semantic (e.g., left inferior frontal gyrus) activation seen at subsequent time points (i.e., T1 & T2) compared to the first timepoint.

3. Additionally, if hearing late learners of sign language show lexico-semantic processing, then it is expected to see greater activation of regions involved in language control and inhibition (e.g., caudate and anterior cingulate cortex) at the same time point as? during? linguistic processing (i.e., T2), given that learners must resolve competition between lexical words and signs in their languages.

Methods

Participants

Twelve (male = 5) hearing English-speaking college students participated in this study. These 12 learners come from a larger study that examined phonetic processing by naive monolinguals, which was T0 in this study (Williams, Darcy, & Newman, 2015). The 12 subjects selected for this study were those students who volunteered to return for two subsequent experimental sessions, providing a full data set to examine longitudinal change in ASL processing. All learners were right-handed according to the Edinburgh Handedness scale ($M = 87.5$, $SD = 19.1$). All learners reported English as their first language. The learners in this study were recruited from introductory American Sign Language (ASL) courses at Indiana University. The learners had little to no exposure to ASL (or any other spoken second language) before enrollment in the ASL course. All learners gave written consent to perform the experimental tasks, which was approved by the Indiana University Institutional Review Board.

At pre-exposure (T0), the learners had a mean age of 20 (1.7). Learners were recruited during their first week of Beginning ASL I enrollment. On average they had 1.06 (range = 0 – 5, $SD = 1.49$) hours of instruction. According to course instructors, the instruction in the first week of classes included introduction to the course, the target language and culture, but little linguistic instruction. Furthermore, most to all instruction was conducted in English during the first week. That is, these learners had minimal to no linguistic knowledge of the target language. Subsequently,

learners had an average of 44.12 (1.00) hours of instruction at T1 and 89.5 (1.95) hours of instruction at T2.

Proficiency Tests

Learners rated their language proficiency and took an ASL vocabulary test at all three time points. The learners rated their proficiency in both English and ASL 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”) for their understanding and fluency abilities. Self-ratings were also collected because previous studies have shown that self-ratings often correlate with measured language proficiency (MacIntyre, Noels, and Clement, 1997; Bachman and Palmer, 1989).

Learners also took a vocabulary test to obtain a gross measure of their proficiency gains over time. A vocabulary test was selected because the following fMRI task only tested lexical processing. Additionally, grammatical knowledge in these early learners would not be well established relative to their lexical knowledge. The test was constructed by taking all of the signs (minus duplicates) from the current ASL textbooks across all 4 semesters of ASL (Smith et al., 1988a, 1988b, 2008). During the vocabulary-translation task, learners viewed video clips of the signed words produced by a native signer. Learners were required to type in the English translation. The computer scored their translations for correct answers, including any synonyms (e.g., *bathroom* or *restroom*

would be accepted for BATHROOM). A total score correct out of 142 was used as the learners proficiency score.

fMRI Task

The experimental design was the same as described in a previous study (Williams et al., 2015). The learners performed a phoneme categorization task at three different time points (T0, T1, and T2). There were 30 trials; the total duration was approximately 9 minutes. Learners viewed a native signer signing words with the speaker's full face and torso shown in front of a blue-gray backdrop. All stimuli were high frequency monomorphemic signs from various word classes. Signs were split into two groups: signs with place of articulation (i.e., location) on the head or face and signs with the location on the body, non-dominant hand, or neutral space (i.e., not on the face). In sign languages, signs contain phonemic subunits called formational parameters. Unlike spoken languages, these parameters include handshape, location, movement, and orientation (Liddell & Johnson, 1989; Sandler, 1989; Brentari, 1998). As such, the participants had to make a phoneme categorization discrimination based on the location parameter when deciding whether a sign was made on various locations of the body. This method was chosen because the task provided an opportunity to force learners to phonetically process the signs by splitting the signs into these two conditions if they knew the signs, but they could still perform the task with no ASL

knowledge, which is most important for performance at baseline (T0). Additionally, this task allowed us to examine the automatic language processing that was expected to occur as the participants became more familiar with ASL.

The functional task was presented in an event-related design. For each trial a 500-millisecond fixation point was presented before the video appeared. Each stimulus video varied in duration ($M = 1593.33$, $SD = 2.53$ ms) and was followed by a jittered interstimulus interval (ISI range = 4000 – 8000, $M = 6000$ ms). Learners were told to press the right index finger for signs that were produced on the face, and to press the left index finger for signs that were produced on the body. They were instructed to make their responses as quickly and accurately as possible. In addition to the ISI, a 30 second fixation was presented at the beginning of the task and was used as a baseline.

Imaging Parameters

Learners underwent 2 scans at each time point (for a total of 6 scans) using a 32-channel head coil and a Siemens 3 Tesla TIM Trio MRI scanner. The first scan was an anatomical T1-weighted scan used to co-register functional images. An MPRAGE sequence (160 sagittal slices; FOV = 256 mm, matrix = 256x256, TR = 2300 ms, TE = 2.91 ms, TI = 900 ms, flip angle = 9°, slice thickness = 1 mm, resulting in 1-mm x 1-mm x 1-mm voxels) was used. The other scan at each time point was the

functional multiband EPI scans for experimental trials (58 axial slices using the following protocol: field of view = 220 mm, matrix = 128x128, iPAT factor = 2, TR = 2000 ms, TE = 30 ms, flip angle = 60°, slice thickness = 2 mm, 0 gap).

Data analysis

Functional images were analyzed using SPM8 (Wellcome Imaging Department, University College, London, UK, freely available at <http://fil.ion.ucl.ac.uk/spm>). During preprocessing images were corrected for slice acquisition timing, and resampled to 2 x 2 x 2 mm³ isovoxels, spatially smoothed with a Gaussian filter with a 4 mm kernel. All data were high-pass filtered at 1/128 Hz to remove low-frequency signals (e.g., linear drifts). Motion correction was performed and motion parameters incorporated into the design matrix. Each participant's anatomical scan was aligned and normalized to the standardized SPM8 T1 template and then fMRI data were co-registered to anatomical images. At the individual level, statistical analysis was performed using the General Linear Model and Gaussian random fields using fixation as the common baseline. The video onsets and durations were entered as regressors in the model (Friston et al., 1995). For the second level (random effects) analysis on group data, paired t-tests were performed for all combinations in order to examine the within-subject change over time. To correct for multiple comparisons, the dimensions and smoothing parameter of processed data

were entered into AFNI's AlphaSim program. With a voxel-wise $p < 0.01$, clusters greater than 62 voxels were considered significant at a corrected alpha = 0.05.

Results

Proficiency Results

At pre-exposure before any ASL exposure, the learners rated their proficiency average scores across both categories were 7 (0) for English and 1.21 (0.37) for ASL. ASL students' vocabulary knowledge ranged from 0 to 15 ($M = 8.08$, $SD = 3.3$) words. Overall, these findings suggest that at pre-exposure (T0), the learners were beginner or naïve ASL learners.

After one semester (approximately 13 weeks later), the learners were brought back for their first post-exposure scan (T1). They rated their ASL ability as a 3.12 (0.82) and their English ability as 7 (0). Course grades were also recorded. Learners had an average of 90.87% (4.26) in their ASL course. Their vocabulary score ranged from 30 – 60 ($M = 44.06$; $SD = 9.5$) words. These results show increased ASL knowledge [vocabulary: $t(11) = 14.61$, $p < 0.0001$] and proficiency [rating: $t(11) = 6.37$, $p < 0.001$] at T1 relative to T0.

After a second semester of ASL training, the learners were brought back for their second post-exposure scan (T2). Learners rated their ASL ability as a 3.92 (0.63). At T2, learners had an average of 91.7% (4.64) in their ASL course. Their vocabulary score ranged from 39 – 66 ($M = 55.83$;

SD = 9.2) words. These results show increased ASL knowledge [vocabulary: $t(11) = 5.03$, $p < 0.001$] and proficiency [rating: $t(11) = 3.58$, $p < 0.001$] at T2 relative to T1.

Behavioral Results

Reaction times were filtered for outliers that were above or below 2 standard deviations from the mean for each subject (1.7%). Reaction times on correct trials were analyzed using a repeated measures analysis of variance (ANOVA) with time (T0, T1, T2) as the factor. Results showed that there was no significant difference across the time points in reaction times for making phoneme categorization [$F(2,22) = 1.433$, $p = 0.260$, eta-squared = 0.115; T0 = 1827 (114) ms; T1 = 1987 (134) ms; T2 = 1802 (134) ms]. Accuracy results showed a similar pattern insofar as there was no significant difference across the time points in accuracy [$F(2,22) = 1.007$, $p = 0.3820$, eta-squared = 0.084; T0 = 96.1% (1.6); T1 = 88.6% (8.0); T2 = 96.7% (1.7)].

Neuroimaging Results

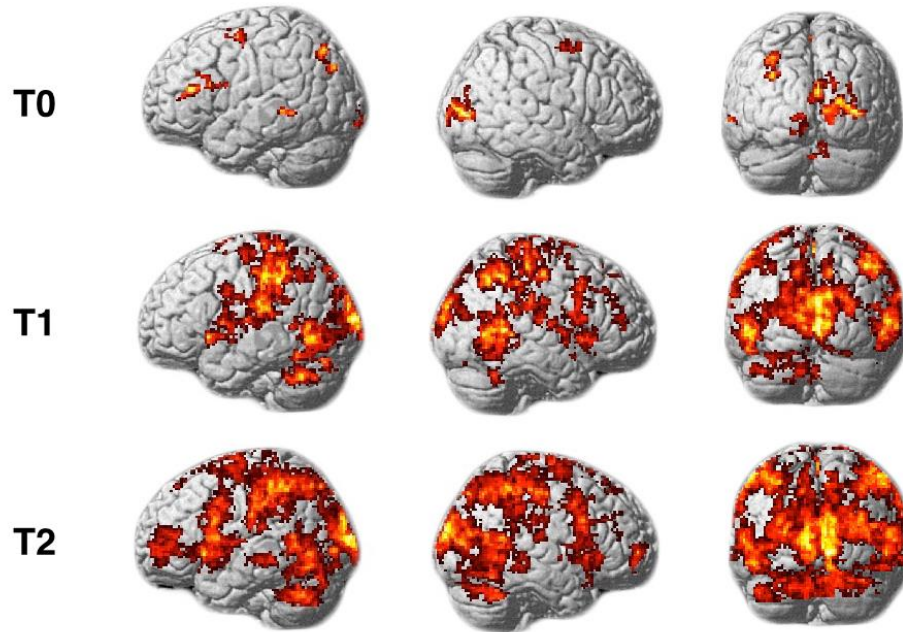


Figure 1. Activation to ASL signs for all three time points: pre-exposure (T0), first post-exposure scan (T1) after 44 hours of instruction, and second post-exposure scan (T2) after 89 hours of instruction.

Table 1 Brain regions activated at each time point (p -corrected < 0.05 ; $k_{min} = 62$)

Cerebral regions (Brodmann Area)	Voxels	MNI coordinates		
		x	y	z
T0				
R cuneus (BA 18)	726	32	-78	4
R supplementary motor area	229	12	-2	60
L superior parietal lobule	191	-32	-72	48
L inferior frontal gyrus/pars triangularis	143	-50	34	16
L middle frontal gyrus (BA 6)	97	-34	-4	58
L calcarine sulcus	77	-4	-102	-8
L posterior cingulate gyrus	73	-4	-28	38
L middle temporal gyrus	70	-56	-38	-2
R middle frontal gyrus	66	32	0	56
R posterior cerebellar lobe (vermis)	62	2	-70	-30
T1				
L middle occipital gyrus (BA 37)	8506	-54	-72	0
L anterior cerebellar lobe	8506	-32	-48	-34

R putamen	5133	30	-14	2
L inferior parietal lobule	3372	-48	-38	48
L cingulate gyrus (BA 24)	1790	-2	-4	48
R middle temporal gyrus	1309	58	-66	2
L caudate	453	-4	12	2
L putamen	453	-28	2	-4
R posterior cingulate gyrus	241	4	-34	26
L postcentral gyrus (BA 4)	203	-20	-28	68
L medial dorsal nucleus	125	-8	-16	10
R culmen	112	36	-56	-30
R inferior frontal gyrus (BA 46)	69	50	44	16
T2				
L cuneus	27669	-8	-82	18
L insula	2592	-40	-2	10
L middle frontal gyrus	637	-42	44	14
R ventral lateral nucleus	487	16	-14	16
L caudate	336	-8	8	14
L cingulate gyrus	227	-2	-32	34
R superior frontal gyrus	213	28	56	2
L middle temporal gyrus	199	-54	-30	-6
L pulvinar	139	-16	-24	6
R postcentral gyrus	118	22	-30	78
L paracentral lobule	71	-14	-42	66

Activation to ASL signs relative to a fixation baseline for each time point can be found in both Figure 1 and Table 1. There was relatively little activation seen for ASL signs relative to fixation at pre-exposure (T0). There was activation in modality-specific areas, such as visual, motor, and spatial processing areas. Activation was seen in visual areas within the occipital lobe, including right cuneus and left calcarine sulcus. The right supplementary motor area was activated during ASL processing. Activation was seen in the left superior parietal lobule. Additionally,

prefrontal cortex was activated during ASL processing, such as left inferior frontal gyrus (pars triangularis), and bilateral middle frontal gyrus.

There was much more activation present in response to ASL signs at the first post-exposure scan (T1). These areas still included modality-specific processing areas, such as left middle occipital gyrus and left inferior parietal lobule for visual processing. However, there was abundant activation of sub-cortical regions, including bilateral putamen, left caudate, and left medial dorsal nucleus of the thalamus. There was additional cingulate activation in both posterior and middle portions. Right recruitment of the inferior frontal gyrus was also seen.

Similar activation was found at the second post-exposure scan (T2) as in T1. These areas included left cuneus, left caudate, left middle temporal gyrus, left cingulate, and right postcentral gyrus. However, there was additional language-related temporal and prefrontal regions, including left insula, middle frontal gyrus, and inferior frontal gyrus. Additional sub-cortical regions were recruited during ASL processing such as the left pulvinar and right ventral lateral nucleus of the thalamus.

To further explore the effect of ASL exposure a contrast analysis was performed to directly compare each time point. Using paired t-tests, the following time points were compared: $T2 > T1$, $T2 > T0$, $T1 > T0$, $T0 > T2$, $T0 > T1$, and $T1 > T2$ (see Figure 2 and Table 2 for results).

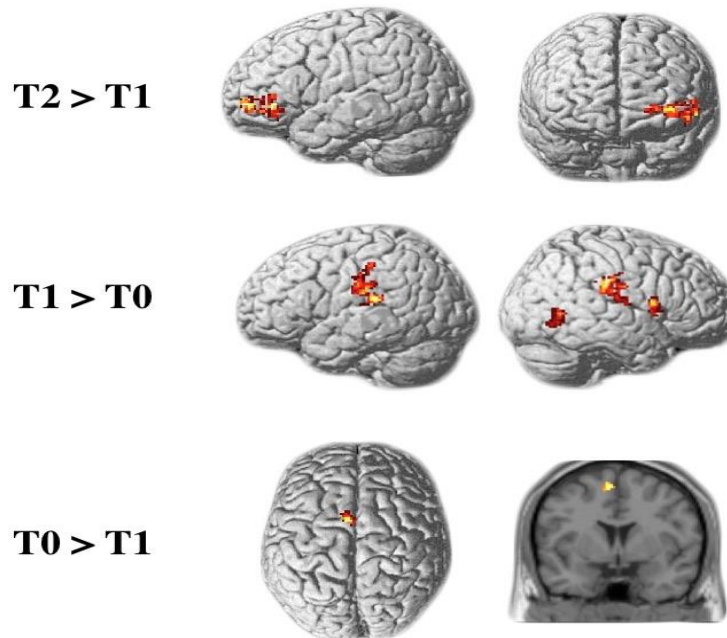


Figure 2. Three contrasts using paired t-tests across the time points at the same corrected $p < 0.05$ at $k = 62$.

Table 2 Conjunction analyses (p -corrected < 0.05 ; $k_{min} = 62$)

Cerebral regions (Brodmann Area)	Voxels	MNI coordinates		
		x	y	z
T2 > T1				
L inferior frontal gyrus (BA 45/47)	134	-48	38	-2
L middle orbital gyrus (BA 10)	115	-34	50	-2
T2 > T0				
L supramarginal gyrus (BA 40)	224	-58	-16	32
R supramarginal gyrus (BA 40)	119	54	-24	30
L insula/rolandic operculum (BA 13)	73	-42	-4	10
L lingual gyrus	129	-12	-70	-8
R inferior frontal gyrus/pars opercularis (BA 44)	74	56	10	14
R inferior frontal gyrus (BA 47)	82	38	16	-20
T1 > T0				
R supramarginal gyrus (BA 40)	268	56	-26	34
L supramarginal gyrus (BA 40)	318	-60	-26	28
R parahippocampal gyrus	112	36	-2	-12
R putamen	62	32	2	4
R inferior temporal sulcus (BA 19)	89	56	-66	-6

R inferior frontal gyrus/pars opercularis (BA 44)	86	54	8	14
T0 > T2				
L supplementary motor area (BA 6)	65	-8	2	62
T0 > T1				
L supplementary motor area (BA 6)	91	-6	2	62

The first post-exposure scan revealed more activation in the inferior temporal sulcus, inferior frontal gyrus, putamen, and parahippocampal gyrus relative to pre-exposure (T1 > T0). These regions were located to the right hemisphere, typical of low-proficiency bilingual language processing (Perani et al., 1998). There was also bilateral supramarginal gyrus activation found for T1 > T0. Similar results were found for the contrast between the second post-exposure scan (T2) and T0. However, there was additional activation in left-hemispheric areas, including the lingual gyrus and insula. The T2 minus T1 contrast revealed activation in left prefrontal regions (inferior frontal gyrus and middle orbital gyrus).

There were no regions found to show increased activation for T1 compared to T2. For both the T0 > T1 and T0 > T2 contrasts, the only significant difference was in the left supplementary motor area (BA 6).

To qualitatively characterize hemispheric recruitment and lateralization across the three time points, the number of voxels that were significantly activated in each hemisphere used to calculate a lateralization index (i.e., $(L-R)/[(L+R)/2]$; see Emmorey et al., 2003). A negative number indicates more voxels were activated in the right hemisphere relative to the left. A positive number is converse, where more activation in the left hemisphere than the right. The lateralization index at the group-level was -

0.498, 1.21, and 1.89 for T0, T1, and T2, respectively. This result indicates a general qualitative left-lateralization with increased language exposure.

Discussion

The goal of the present study was to characterize the neural processing of sign language during second language acquisition by hearing adults. By studying hearing adults acquiring sign language as a second language, the functional changes that occur during the acquisition of a language that is perceived and produced in another sensorimotor modality was directly tested. A second goal of the present study was to investigate these changes as a function of time by studying within-subject changes using a longitudinal design. A longitudinal design provides unique insights into neural changes over time relative to cross-sectional studies because changes can be observed while controlling for individual differences in cognition and experience. In the present study it was found that modality-specific processing precedes amodal linguistic processing during second language acquisition. Rapid changes to functional processing of sign language, lateralization, and language control mechanisms after only one semester of instruction were observed. As such, this is the first study to demonstrate neural changes in the processing of sign language while acquiring new language modality itself.

T0 activation

Activation at pre-exposure, before any significant sign language exposure, was sparse. Reduced activation while processing ASL signs can be attributed to the learners' lack of awareness of their linguistic properties. As such, learners likely processed the stimuli by focusing only on the visual-motor properties, which explains the increased activation in modality-specific processing areas. The posterior visual sensory activation was found in the calcarine sulcus, cuneus, as well as the posterior cingulate cortex. Previous studies have shown that deaf signers have greater grey matter volume in the calcarine sulcus, indicative of more intense, complex visual processing (Allen, Emmorey, Bruss, & Demasio, 2013). Additionally, previous functional imaging data has shown evidence for increased activation to British Sign Language signs in both the calcarine and cuneus relative to a static baseline (MacSweeney et al., 2006). The cuneus has also been implicated in nonlinguistic event perception, like watching movies of making the bed or other household chores, as well as biological motion of point-light displays (Servos, Osu, Santi, & Kawato, 2002; Speer, Swallow, & Zacks, 2003; Vaina et al., 2001; Zacks et al., 2001; Zacks, Swallow, & Vettel, 2006). The posterior cingulate activation observed here may be related to motion processing. For example, Cornette and colleagues (1998) found the posterior cingulate gyrus showed greater activation for onset of motion of dynamic dots relative to stationary dots. Together, these studies point to a more

general motion and event processing of linguistic sign language stimuli at pre-exposure.

In addition to visual activation other modality-specific activation was found in the supplementary motor area (SMA) and superior parietal lobule. The SMA has been shown to not only be involved in the production of language, but also in the *perception* of human actions (Decety & Grezes, 1999; Grezes, Costes, & Decety, 1998). The superior parietal lobule (SPL) has been associated with spatial-motor behavior (Grafton et al., 1996; Grefkes et al., 2004) and multisensory integration (Molholm et al., 2006). Additionally, the parietal lobe (including the superior parietal lobule) has been shown to be activated during sign language comprehension and production (Corina & Knapp, 2006; Emmorey et al., 2002, 2003; MacSweeney et al., 2002). Therefore, the SMA and SPL activation at T0 suggests that learners were focusing on the visuo-motor properties of the stimuli.

Other pre-exposure activation could be attributed to lack of prior sign language knowledge. Activation in the left inferior frontal gyrus may be due to hierarchical sequence processing (Clerget, Winderickz, Fadiga, & Oliver, 2009; Dominey et al., 2003; Fazio et al., 2010). The task of determining whether the sign was produced on the face requires the participant to segment a sequence of movements and categorize parts of that sequence. This is analogous to phonemic segmentation tasks that have been shown to activate the left IFG in both spoken (Burton, Small, &

Blumstein, 2000, Newman et al., 2001; Zatorre, Evens, Meyer, & Gjedde, 1992; Zatorre, Meyere, Gjedde, & Evens, 1996) and sign languages (Williams, Darcy, & Newman, 2015). A previous study examining differences in sign language and non-linguistic action processing in hearing nonsigners showed left IFG and ventral premotor activation, which was also attributed to the mirror neuron system and human action processing (Corina et al., 2007). As such, similar activation in the present study at pre-exposure (T0) may indicate non-linguistic processing of signs for our hearing learners.

Activation in the posterior middle temporal gyrus could also be due to the learners' lack of vocabulary knowledge, given that pseudowords have been shown to activate the pMTG (Davis & Gaskell, 2009; Price, 2010). Additionally, degraded low-cloze speech activates bilateral posterior middle temporal gyrus (Obleser & Kotz, 2010). However, it is probable that activation in left middle temporal gyrus may be attributed to biological motion processing (in addition to the cuneus and posterior cingulate as indicated above). Pelphrey and colleagues (2005) found activation to the processing of eyes and mouth in the right homologue of the middle temporal gyrus ($x = 62, y = -40, z = -4$), similar to what was found in this study on the left ($x = -56, y = -38, z = -2$).

It should be noted that the above activation found for T0 in these 12 learners was largely the same as that found for a larger group of naïve monolinguals presented in Williams et al. (2015). Activation in the left

prefrontal cortex, bilateral parietal lobes, and visual cortex were the same across both studies. However, there was additional activation in the posterior temporal lobe in the present study. Additional posterior temporal activation may be simply due to individual differences within the subgroup of 12 learners in this study that may have been washed out in the larger group of learners in Williams et al. Nevertheless, largely consistent findings in larger clusters signify that the subset of learners in the present study is likely representative of a larger group of learners.

T1 activation

After one semester of ASL training there was increased activation in several brain regions in response to ASL. There was still persistent modality-specific activation seen in regions such as the left middle occipital gyrus and right posterior cingulate gyrus. There was also significant cerebellar activation in both the left anterior lobe and the right culmen, which are involved in motor planning, articulatory processes, and language processing (Desmond & Fiez, 1998; Nitscheke, Kleinschmidt, Wessel, & Frahm, 1996). Additional hand processing activation was seen in the right inferior temporal sulcus (BA 19). This area has been found to be more activated for hand motion than face motion (Thompson, Hardee, Panayiotou, Crewther, & Puce, 2007). Motor-based activation in the cerebellum and inferior temporal sulcus suggest further changes of the neural requisites for processing a new sensorimotor modality, especially

for that of hand processing. Acquisition of hand processing is often protracted for second language learners of ASL insofar as they often focus on the hands more than native signers, especially at lower proficiency levels (Morford & Carlson, 2011).

When examining the contrast between the first post-exposure scan and pre-exposure ($T1 > T0$), there was also greater bilateral supramarginal gyrus activation. The presence of bilateral supramarginal activation is consonant with greater phonological processing (Hartwigsen et al., 2010; Sliwiska et al., 2012; Stoeckel et al., 2009). Hartwigsen et al. (2010) demonstrated disruption to phonological judgments when transcranial magnetic stimulation was applied over the left supramarginal gyrus. This is consistent with a number of other findings that have implicated the left supramarginal gyrus in phonological processing (Romero, Walsh, & Papagno, 2005).

The putamen was also activated at T1. The putamen is functionally connected to the left IFG and subcortical regions provide cortical initiation of phonological representations (Booth, Wood, Lu, Houk, & Bitan, 2007). Greater phonological processing, as implicated by supramarginal gyrus activation in addition to greater hand processing, as implicated by cerebellar, putaminal, and inferior temporal sulcus activation, indicate that by the end of the first semester learners have transitioned into being able to process signs phonologically. As such, a primary speculation that can be inferred from the difference between activation at pre-exposure and

after one semester of input is that the learner transitions from a more general motion processing strategy to a more phonologically-based strategy.

T2 activation

After the second semester (T2), there was greater language-related activation, especially in the left insula and left IFG. The subregion of the left inferior frontal gyrus active at T2 is involved in word retrieval and lexico-semantic processing (Heim, Eickhoff, & Amunts, 2009; Price, 2010; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). The left insula has also been implicated in language processing including word finding, language comprehension, and articulation (Ardila, Benson, & Flynn, 2007). Increased activation at T2 in the left IFG and insular regions suggests a transition from phonological processing to lexico-semantic processing. MEG studies of hearing late L2 learners also found lexico-semantic processing in fronto-temporal regions during early stages of acquisition (Ferjan et al., 2013; Leonard et al., 2013). Therefore, the present neuroimaging study was able to demonstrate sequential stages in which a hearing adults learning sign language moves through transitory stages from domain-general processing, to phonological processing, and subsequently to lexico-semantic processing — all of which takes about one year of instruction.

Although learners showed neural activation patterns suggestive of more thorough sign processing and phonological processing at T2, they did not show more accurate or faster performance on the behavioral task. One might expect that enhanced L2 proficiency would positively impact phoneme categorization. However, there may be several reasons for this null effect. First, it is likely that having only 12 learners did not provide enough power for behavioral differences to arise across time. Second, given that this task was also a spatial discrimination task, which could utilize domain-general spatial cognition skills, it is likely that additionally ASL exposure may not advantage these learners on this specific task. Lastly, it is possible that the task was too easy (i.e., T0 accuracy = 96.1%) and ceiling effects prevented from proficiency effects to arise. Nevertheless, the neural results presented herein are still representative of the changes at the neural level, despite absence of behavioral effects. This distinction is meaningful because it demonstrates neural changes during second language learning that are independent of task.

Right hemisphere recruitment

During acquisition, typical right hemisphere recruitment with a trend towards left lateralization was found. Greater right hemisphere recruitment starting at T1 and persisting to T2 is consonant with previous work on unimodal bilingual language acquisition. Bilinguals may have greater right hemisphere activation relative to monolinguals (Perani et al., 1998).

However, activation during language processing often converges to a left-lateralized language network with increased proficiency (Abutalebi & Green, 2007). Thus, it is somewhat unsurprising to find similar left-lateralization for these learners over time, where there was greater recruitment of the right hemisphere at T0 than T1 or T2. However, ASL learners still had right-hemisphere activation at later time points, which is similar to native signers (Neville et al., 1998; Bavelier et al., 1998). However, it was found in the present study that learners had right angular gyrus [45 -65 47] activation at T2 (SVC $p_{\text{FWE}} < 0.05$). A previous study showed a critical period for right angular gyrus activation wherein only early signers, either monolingual or bilingual, showed right angular gyrus activation, but this was not present for those who learned sign language after puberty, like those learners in the present study (Newman, Bavelier, Corina, Jezzard, & Neville, 2001). Thus, this may be the first evidence for specialization of sign language processing for *late* (i.e., after puberty) learners of sign language, which is not constrained by age of acquisition.

Language control

Another area in which there is debate about learners of sign language is their ability to control both languages. A previous study showed that there is no bilingual advantage for native bimodal bilinguals in their ability to inhibit a prepotent response, which was argued to be due to divergence between the language modalities (Emmorey, Luk, Pyers, &

Bialystok, 2008). However, recent neural findings point to the need for language control in speech-sign bimodal bilinguals. Zou et al. (2012) found that bimodal bilinguals had greater grey matter volume in the left caudate nucleus, a region known for its involvement in language control (for review, see Abutalebi & Green, 2008). The authors argued that bimodal bilinguals indeed need inhibitory control to navigate between their two languages, regardless of modality differences. The present study extends these findings as there were many areas activated that are often implicated in language control. The first emergence of this type of activation was after the first semester of exposure where left caudate activation was observed. Left caudate activation was persistent through T2, which suggests that language control mechanisms were required up to at least 10 months of instruction. Typically, lower proficiency learners require more language control than those with higher proficiency, and as such, this suggests that within the first year of language acquisition, bimodal bilinguals still require a large amount of control, despite the divergence between the modalities. To drive home this point, there was also activation in the left anterior cingulate gyrus at T1, which has also been found to be involved in language control (Abutalebi et al., 2008; Abutalebi & Green, 2008). With activation of the left caudate and anterior cingulate cortex, this study was able to provide evidence that late L2 learners of ASL may exhibit language control when processing ASL despite the modality differences.

An alternative explanation for the involvement of the caudate and the anterior cingulate is that their activation may also be indicative of less automatic language processing (Friederici, 2006). Given that these learners were in very early stages of L2 acquisition sign language processing may be less automatic, more effortful and error prone. As such learners may be expected to require more controlled processing from the left caudate that is unrelated to managing two languages. Nevertheless, it could be argued that greater controlled processing is the very role of the left caudate in language control, especially for bilinguals (Zou et al., 2012). Taken together, activation in the left caudate (and anterior cingulate cortex) may provide causal evidence that language control (or more controlled processing) is involved in bilingual processing, regardless of language modality. However, it should be noted that since there was no specific contrast within the present study to directly test language control, these findings are only speculative in nature.

Limitations

The method in our current study was able to tap into both spatial and linguistic processing regardless of the learners' knowledge of sign language. However, the present method did not have a non-linguistic spatial baseline to ensure that neural changes across time were due to sign language knowledge and not spatial attention. It has been shown previously that there is a dorsal frontoparietal network that is engaged

during spatial attention (Corbetta & Shulman, 2002). Many of the regions that showed increased activation at T1 and T2 compared to baseline (T0) belong to this frontoparietal network. Thus, it may be the case that the activation seen in the parietal and temporal lobes at T1 and T2 are not solely due to linguistic knowledge, but rather enhanced spatial attention processing. Although we cannot fully rule out this possibility, the present findings are impactful nonetheless for a number of reasons. First, given that this task is a (uncued) simple spatial task that does not require working memory and learners can use relatively easy domain-general spatial processing to complete the task, we would expect little activation due to attention rather than language. Moreover, given that activation in frontoparietal lobes was correlated with the acquisition of vocabulary items, we would argue that this activation is more suggestive of phonological processing. Second, we would not argue that spatial attention is not required during sign language processing; therefore, increased activation in the frontoparietal network due to attentional enhancements is indicative of enhanced signed language processing too. Taken together, we would argue that the present study was able to demonstrate time-specific changes to the neural processing of sign language that followed modality-specific (e.g., visuospatial) to a more modality-independent (e.g., attention, amodal linguistic, etc.) processing. Furthermore, any concomitant enhancements in spatial attention due to L2

sign language acquisition would be a further indication that learners are learning to process linguistic stimuli more robustly.

Conclusion

The present study tracked activation pattern differences in response to sign language processing by late learners of American Sign Language. Learners were scanned before the start of their language courses and twice more during their first two semesters (10 months) of instruction. The study aimed to characterize modality-specific to modality-general processing throughout the acquisition of sign language. Neural substrates related to modality-specific processing (e.g., visual and action processing) were present. Learners transitioned into processing signs on a phonological basis (e.g., supramarginal gyrus, putamen) before transitioning once more to a lexico-semantic processing stage (e.g., left inferior frontal gyrus) at which time language control mechanisms (e.g., left caudate, cingulate gyrus) came online. In conclusion, the present study is the first to track L2 acquisition of sign language learners for a better understanding of modality-independent and modality-specific mechanisms during bilingual language processing.

Chapter 3: Poor Language Outcomes

This chapter is currently under review, but the formatting has been slightly modified for the purposes of this dissertation:

Williams, J.T., Darcy, I., Newman, S.D. (in review). Poor M2L2 sign language vocabulary knowledge engages modality-independent lexico-semantic and modality-dependent hand and movement neural processing. *Bilingualism Language and Cognition*.

Introduction

Many recent studies have explored how adults acquire a second language (for review see Kroll et al., 2015). These studies typically include hearing adult learning whose first language is a spoken language and are subsequently acquiring another spoken language. In comparison, relatively fewer studies have investigated individuals who have one spoken language and one sign language (i.e., bimodal bilinguals or M2L2 learners). Furthermore, the study of the bimodal bilingual brain has been mostly restricted to native bimodal bilinguals who acquired their languages simultaneously (Emmorey & McCullough, 2009; Emmorey et al., 2005, 2015). Thus, it is important to expand our knowledge of sign language acquisition after a spoken language has already been established (Li et al. 2015; Zou et al., 2012). Given that many adults are learning sign languages as a second language (L2) and these two languages require different sensorimotor modalities (M2), M2L2 learners of sign languages are the perfect test case to explore modality-independent and modality-dependent neural mechanisms for L2 acquisition.

There have been several previous neuroimaging studies that have investigated the neural substrates of L2 vocabulary processing as well as functional and structural changes due to increasing proficiency (Grant, Fang, & Li, 2015; Perani & Abutalebi, 2005; Saidi et al., 2013; Stein et al., 2006, 2012). For instance, bilinguals demonstrate prefrontal engagement during L2 lexico-semantic processing, which diminishes with increased L2

proficiency (Grant et al., 2015). Similar structural plasticity has been observed in left prefrontal areas (e.g., inferior frontal gyrus, IFG), such that higher proficiency learners have greater grey matter volume in the left IFG than low proficiency learners. Decreased functional activity and increased grey matter volume are thought to represent enhanced automaticity of lexico-semantic processing, which is a function of proficiency (Grant et al., 2015; Ishikawa & Wei, 2009; Stein et al., 2012). Also, there is evidence that greater activation of cognitive control regions is required due to parallel competition between lexical items at initial stages of lexical acquisition (Abutalebi, 2008; Grant et al., 2015; Van Hell & Tanner, 2012). Despite our growing knowledge of the neural substrates of L2 (within-modality) lexical acquisition, we still know relatively little about the acquisition of lexical signs.

The study of second language acquisition of sign language in adulthood is important to both our understanding of neuroplasticity and second language theory. Sign languages differ substantially from spoken languages in their primary articulators. Sign languages rely on arbitrary manual-visual phonetic codes to convey messages. Additionally, sign languages exploit the use of spatial dependencies for grammatical and discourse purposes (Sandler & Lillo-Martin, 2006). The phonology of sign languages, as such, includes sublexical features that relate to the hands in space. The primary sublexical features of manual signs are hand configuration, palm orientation, place of articulation, and movement (Baker

et al., 2016; Brentari, 1998). Therefore, tracking of hands through space is important for the lexico-semantic processing of sign languages. Given that bimodal bilinguals and M2L2 learners are hearing adults who have experience with both spoken language (oral-auditory modality) and sign language (manual-visual modality), it is of prime interest to understand both the modality-specific and amodal aspects of language acquisition and neuroplasticity.

Studies on simultaneous bimodal bilingualism have delineated differences and similarities in speech and sign processing. Bimodal bilinguals (who acquired their two languages simultaneously) show greater activation in the bilateral parietal cortex and bilateral occipitotemporal cortex during single sign comprehension (Emmorey et al., 2014; Söderfeldt et al., 1997). These areas are thought to be unique to the processing of sign languages, and have been activated by spatial classifiers and verbs in American Sign Language (ASL) in addition to other demanding visual processing tasks. Sequential bimodal bilinguals show additional involvement of regions associated with language control (Li et al., 2015; Zou et al., 2012). However, the time course for developing such activation patterns in late learners is unclear. Moreover, little is known about the changes in processing that occur in the bimodal bilingual or M2L2 learner brain between the initial, naïve state of learning and a more proficient level of language knowledge. Perhaps learners attempt to process lexical signs as gestures, but move towards lexico-semantic

processing with time (see Williams, Darcy, & Newman, 2016). Additionally, there is behavioral evidence that late M2L2 learners of sign language often have difficulty acquiring the visual-manual characteristics of the target sign language. Specifically, not only learners have difficulty acquiring sign language movement, but they also show an overreliance on the handshape of the sign (Bochner et al., 2011; Chen Pichler, 2011; Grosvald, Lachaud, & Corina, 2012; Morford et al., 2008; Morford & Carlson, 2011; Rosen, 2012; Schlehofer & Tyler, 2016; Williams & Newman, 2015, 2016). Therefore, it may be that the ability to acquire an L2 sign language is based on the ability to have automatized processing in regions involved in spatial processing, biological motion, and hand processing, which subserve visuomotor phonetic processing.

A previous longitudinal neuroimaging study showed that M2L2 learners of ASL progressed stepwise through stages of lexical processing (Williams, Darcy, & Newman, 2016). Before exposure to sign language the learners processed ASL lexical signs using non-linguistic (or at least phonetic) regions implicated in visuospatial and motor processing, with significant activation in occipital (e.g., calcarine sulcus) and parietal (e.g., superior parietal lobule) lobes. After one semester of exposure, the learners show greater cortical recruitment in supramarginal gyrus and putamen, suggesting that they transitioned into a phonological processing stage. Subsequently, the learners transitioned into a lexico-semantic processing stage after 10 months of exposure, where they recruited more

activation in the left inferior frontal gyrus. It is possible that the progression of lexical processing is different for those who are poor learners, which was not investigated in the aforementioned study. It could be posited that poor vocabulary learners perseverate on the modality-specific aspects of sign language (e.g., visuospatial and visuomotoric features), or do not fully automatize such processing routines, which may block or delay successful sign language acquisition.

Given the gap in knowledge about M2L2 sign language acquisition, the present study aimed to characterize the neural substrates of vocabulary acquisition and lexical sign processing in hearing M2L2 learners of American Sign Language (ASL) at early stages of acquisition. Specifically, there were three main aims of the present study:

The first aim was to characterize the pattern of vocabulary acquisition across the first year of instruction. Not only has there not been a prior study that has examined the lexical acquisition trajectory of M2L2 learners in foreign language classrooms, which is theoretically motivated, but also it is meaningful from an applied perspective so that we can better understand whether acquisition rates change during certain semesters. The expectation, of course, was that students would acquire new lexical knowledge in a relatively equal stepwise fashion.

Second, since learners have little knowledge of sign language at the start of their L2 instruction, we aimed to characterize how limited vocabulary knowledge affects M2L2 sign language processing. The

individual variability in brain response prior to learning may be predictive of future attainment. For example, we hypothesized that students who later have a smaller sign vocabulary process lexical signs as holistic visual objects instead of decomposable linguistic objects which is how we hypothesize that those who later develop a larger sign vocabulary. This difference in initial processing, again, is expected to be observed in the brain activation patterns and will impact later learning.

Our third aim is to how gains in vocabulary knowledge affect neural processing after 10 months of L2 instruction. Specifically, we examined whether the poor vocabulary learners persisted with the holistic processing strategy after one year of instruction, or whether their strategy had shifted. We hypothesized that perhaps continued processing of signs using areas dedicated to biological motion (e.g., temporoparietal and occipitotemporal) and hand (e.g., intraparietal sulcus, putamen) processing would suggest the use of relatively less efficient strategies that focus on decoding the movement. Furthermore, given the year-long exposure to lexical signs, we might expect greater phonological and/or lexico-semantic processing (e.g., inferior frontal gyrus (IFG); “Broca’s area”) at T2 because previous studies have shown lower proficiency learners recruit greater activation in IFG when viewing lexical items (Grant et al., 2015).

By examining these questions, the present study was able to elucidate how vocabulary knowledge affects the neural processing of ASL.

Theoretically, it was aimed to corroborate behavioral studies that have characterized deficits in M2L2 acquisition. From a practical perspective, if the neurocognitive profiles of poor vocabulary learners can be identified, which may be indicative of a global sign language deficit, then potential classroom interventions that aim to improve M2L2 acquisition can be developed to address those deficiencies. We aimed to answer these questions using a longitudinal design in two different experiments. First, Experiment 1 tracked the changes in vocabulary knowledge over 10 months, or two semesters, of ASL exposure. Experiment 1 was included in order to address our first aim and to determine whether our subset of learners was representational of a larger sample. Experiment 2 examined the pattern of neural activation in response to viewing ASL lexical signs before and during their L2 instruction for 10 months in a subset of 12 hearing adult learners of ASL from Experiment 1. The use of a longitudinal neuroimaging design affords us the opportunity to examine vocabulary acquisition without the confounding factors that plague cross-sectional designs (e.g., different brains, language and scholastic experiences, instructors, coursework, etc.).

Experiment 1: Behavioral Changes in Vocabulary Acquisition

Materials and Methods

Participants

Thirty-four (male = 10) hearing English-speaking college students participated in Experiment 1. All participants were right-handed according to the Edinburgh Handedness scale ($M = 85.6$, $SD = 19.1$). All participants reported English as their first language. The participants in this study were recruited from introductory American Sign Language (ASL) courses at Indiana University. The participants had little to no exposure to ASL (or any other spoken second language) before enrollment in the ASL course. All participants gave written consent to perform the experimental tasks, which was approved by the Indiana University Institutional Review Board.

At baseline (T0) the 34 participants had a mean age of 20.6 (2.5). Participants were recruited during their first week of Beginning ASL I enrollment. On average they had 1.06 (range = 0 – 5, $SD = 1.49$) hours of instruction. According to course instructors, the instruction in the first week of classes included introduction to the course, the target language and culture, but little linguistic instruction. Furthermore, most to all instruction was conducted in English during the first week. That is, these participants had minimal to no linguistic knowledge of the target language. Additionally, the participants rated their proficiency in both English and ASL 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”) for their understanding and fluency abilities. Their average scores across both categories were 7 (0) for English and 1.15 (0.31) for ASL.

After one semester (approximately 13 weeks later), the participants were brought back. Twenty-five participants (male = 7) returned for their first post-exposure follow-up (T1). On average they had 43.98 (1.12) hours of instruction. They rated their ASL ability as a 3.32 (1.05) and their English ability as 7 (0). Course grades were also recorded and they received an average of 91.12% (4.87) in their ASL course.

After a second semester of ASL training, 12 participants (male = 5) returned for their second post-exposure session (T2). On average they had 89.5 (1.95) hours of instruction and rated their ASL ability as a 3.92 (0.63). At T2, participants had an average of 91.7% (4.64) in their second ASL course.

Procedure

Participants took a vocabulary test to obtain a gross measure of their vocabulary knowledge over time. The test was constructed by taking the signs from the current ASL textbooks across all four semesters of the current ASL curriculum (Smith et al., 1988a, 1988b, 2008). Based on data retrieved from ASL-LEX (Caselli et al., 2016), the signs included in this test were 142 signs total and were relatively high frequency (M = 4.59, SD = 1.16; very frequent = 7, infrequent = 1) and were arbitrary (M = 2.29, SD = 1.69; very iconic = 7, arbitrary = 1). During the speeded vocabulary-translation task, participants viewed video clips of the signed words produced by a native signer only once (Figure 3). Participants were

required to type in the English translation (or a guess) within five seconds. An automated procedure was used to score their translations for correct answers, including any synonyms (e.g., *bathroom* or *restroom* would be accepted for BATHROOM). A total score correct out of 142 was used as the participants proficiency score.

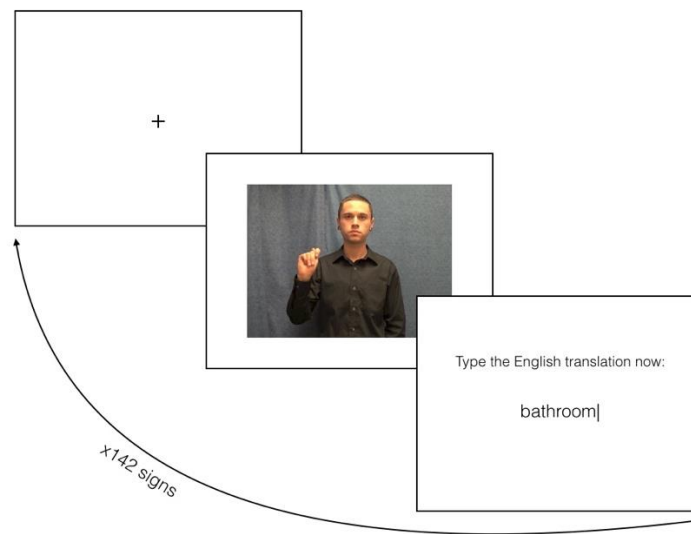


Figure 3. Design of speeded vocabulary-translation task.

Statistical Approach

Two different analysis methods (R software) were used to analyze the changes in vocabulary knowledge across the three time points. Given that there was attrition in the number of subjects over time, the statistical methods needed to account for missing data. A typical analysis of variance would not be appropriate for missing data, or different sample sizes, across each time point. Therefore, two methods that are robust to missing data were used. First, a predictive mean matching method ($k = 5$)

was used, in which missing values from the attrited participants were imputed and accessed using pooled data across multiple regressions (Landerman, Land, & Pieper, 1997). Including T1 was not only advantageous because it improves the imputation approach by contributing more data, but also it provides clearer understanding of vocabulary growth over time. Given some downsides to imputation (see Landerman et al., 1997), a linear mixed-effect model was also performed (Verbeke & Molenberghs, 2009). Both methods have their respective downsides when it comes to missing data; thus, any convergence of results between the two models as taken as an indicator of confidence. A correlation was performed between T0 and T2 scores with the vocabulary growth ($\text{Vocab}_{T2} - \text{Vocab}_{T0}$) for the 12 recurrent subjects to investigate whether the change was due to performance at baseline or after sign language exposure.

Results

Figure 4 illustrates the average vocabulary score for the ASL learners at each time point. The regression results showing the size of vocabulary increases over time are presented in Table 1. Results from the pooled regressions after missing data was estimated with ten imputations found that the intercept coefficient has a value of 7.03 (SE = 2.11), T1 has a value of 35.9 (SE = 4.78), and T2 has a value of 40.4 (SE = 12.80). This indicates that relative to the baseline, there was a large and significant

increase in vocabulary scores at T1 ($t = 7.52, p < 0.001$), while T2 only further increased the outcome by around five lexical signs ($t = 3.16, p < 0.05$). T-values were large (greater than 2.0) after both semesters and have p -values less than 0.05, meaning the differences are statistically significant when comparing them to the baseline. Results from the linear mixed-effects model corroborated these findings. There was a significant increase relative to baseline for both T1 ($t = 17.58, p < 0.001$) and T2 ($t = 17.09, p < 0.001$).

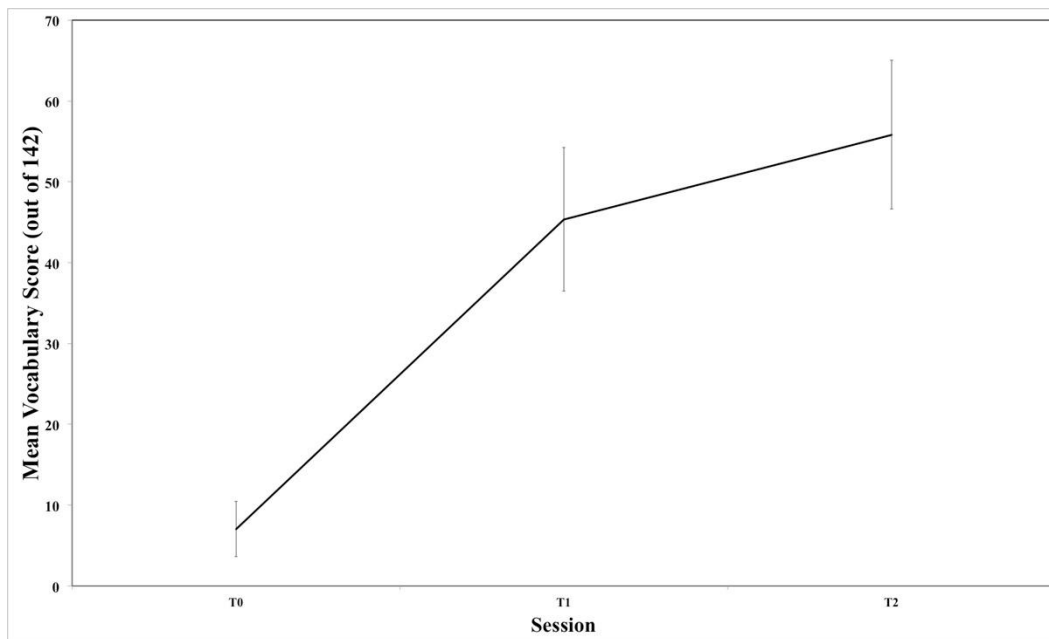


Figure 4. Mean vocabulary scores at each time point averaged across all subjects.

Table 3. Vocabulary scores at each time point

Variable	M	SD	range
T0	7.22	3.42	

T1	45.48	8.75
T2	55.83	9.19

No significant correlation was found between vocabulary growth and T0 gross vocabulary score [$r = 0.218$, $p = 0.496$], but there was a significant correlation between vocabulary growth and T2 gross vocabulary score [$r = 0.918$, $p < 0.0001$]. Therefore, those who had the largest increases in their score also had the largest T2 vocabulary, but the increase was not dependent on their baseline vocabulary score at T0.

Experiment 2: Neural Correlates of M2L2 Vocabulary Acquisition

Materials and Methods

Subjects

The learners in Experiment 1 also participated in several neuroimaging sessions. However, due to significant amount of attrition, only 12 subjects that attended all three neuroimaging sessions. Thus, Experiment 2 only included these 12 learners in the multiple regression analysis of the BOLD responses to ASL lexical signs. A longitudinal design allows for the change over time in the neuroimaging data to be attributed to the subjects and not to an effect of different number of subjects at each time point or other factors between groups in a cross-sectional study.

All 12 learners (male = 5) were right-handed according to the Edinburgh Handedness scale ($M = 87.5$, $SD = 19.1$) with a mean age of

20 (1.7). All participants reported English as their first language. On average they had 1.06 (SD = 1.49), 44.12 (SD = 1.00), and 89.5 (SD = 1.95) hours of instruction at T0, T1, and T2, respectively. These learners self-rated their ASL ability as 1.21 (SD = 0.37), 3.12 (SD = 0.82), and 3.92 (SD = 0.63) at T0, T1, and T2, respectively. The learners also had an average of 90.8% (SD = 4.26) and 91.7% (SD = 4.64) in their ASL course at T1 and T2, respectively.

The mean number of vocabulary signs known for this subset of learners was 8.08 (SD = 3.3), 46.06 (SD = 9.5), and 55.8 (SD = 9.2) at T0, T1, and T2, respectively. These values (i.e., age, handedness, hours of exposure, grades, or self-rating) are consistent with the overall sample descriptive statistics thus they suggest that this subset of learners can be treated as a representative sample of the larger L2 ASL learners from Experiment 1.

Procedure

The impact of vocabulary knowledge on L2 sign language processing was also tracked using functional magnetic resonance imaging (fMRI). The participants performed a short phoneme categorization task with thirty categorization trials in total. The task took about 9 minutes. Participants viewed a native signer signing words with the speaker's full face and torso shown in front of a blue-gray backdrop. All stimuli (see Appendix) were high frequency monomorphemic signs from various word

classes (i.e., nouns, verbs, adjectives; Caselli et al., 2016). Signs were split into two groups: signs with place of articulation (i.e., location) on the head or face and signs with the location on the body, non-dominant hand, or neutral space (i.e., not on the face). Recall that place of articulation (or location) is a sublexical feature of sign language and is considered similar to a phoneme (Baker et al., 2016; Brentari, 1998; Sandler & Lillo-Martin, 2006). As such, this task is in essence a phoneme classification task. The selection of face and not-face locations was to match for the bilabial (visible on the face) and non-bilabial (not visible on the face) task that was implemented in Williams et al. (2015, 2016), while still being phonologically valid in ASL. Although the task itself was meaningless, it required participants to phonetically process the signs by splitting the signs into these two conditions, which the viewing of signs was thought to engage automatic lexical processing (similarly for audiovisual speech, see Campbell et al., 2011).

The functional task was presented in an event-related design. For each trial a 500-millisecond fixation point was presented before the video appeared. Each stimulus video varied in duration ($M = 1593.33$, $SD = 2.53$ ms) and was followed by a jittered interstimulus interval (ISI range = 4000 – 8000, $M = 6000$ ms). Participants were told to press the right index finger for signs that were produced on the face, and to press the left index finger for signs that were produced on the body. They were instructed to make their responses as quickly and accurately as possible. In addition to

the ISI, a 30 second fixation was presented at the beginning of the task and was used as a baseline.

Imaging Parameters

Participants underwent two scans using a 32-channel head coil and a Siemens 3 Tesla TIM Trio MRI scanner. The first scan was an anatomical T1-weighted scan used to co-register functional images. An MPRAGE sequence (160 sagittal slices; FOV = 256 mm, matrix = 256x256, TR = 2300 ms, TE = 2.91 ms, TI = 900 ms, flip angle = 9°, slice thickness = 1 mm, resulting in 1-mm × 1-mm × 1-mm voxels) was used. The remaining scans were the experimental functional multiband EPI scans (59 axial slices using the following protocol: field of view = 220 mm, matrix = 128x128, iPAT factor = 2, TR = 2000 ms, TE = 30 ms, flip angle = 60°, slice thickness = 3.8 mm, 0 gap).

Data analysis

Functional images were analyzed using SPM8 (Wellcome Imaging Department, University College, London, UK; freely available at <http://fil.ion.ucl.ac.uk/spm>). During preprocessing images were corrected for slice acquisition timing, and resampled to 2 mm³ isovoxels, spatially smoothed with a Gaussian filter with a 4 mm³ FWHM kernel. All data were high-pass filtered at 1/128 Hz to remove low-frequency signals (e.g., linear drifts). Six-parameter rigid body motion correction was performed and

motion parameters incorporated into the design matrix as nuisance regressors in the General Linear Model (GLM). Each participant's anatomical scan was aligned and normalized to the standardized SPM8 T1 template and then fMRI data were co-registered to high-resolution anatomical images.

At the individual (first) level, statistical analysis was performed using the standard GLM with Gaussian random fields in SPM8. The ASL stimulus onsets and durations were entered as our main regressors in the GLM in order to model the hemodynamic response function with stimulus events (Friston et al., 1995). BOLD signal from a common fixation baseline was subtracted from BOLD related to viewing ASL signs and was used as our estimated contrast. For the second level analysis on group data, multiple regression analyses were performed at each time point (T0 and T2) using each subject's ASL-Fixation contrast with each learner's respective vocabulary score at that time point entered as a covariate. Vocabulary score was the only covariant added to the model. Given that vocabulary scores were relatively the same between T1 and T2, we decided to only include T2 in the current analysis; additionally, T2 was thought to maximize the potential of finding neuroplastic effects given that it was approximately 10 months post-baseline compared to 3 months at T1 and had the highest amount of variability in vocabulary scores. To correct for multiple comparisons, the image dimensions and the smoothing parameter of the processed data were entered into AFNI's 3dClustSim

program in order to determine cluster sizes that would be significant given our voxel-wise p-value. Given the results of 5000 Monte Carlo simulations, both positive and negative regressions were performed using a voxel-wise $p < 0.005$, which was corrected to $\alpha < 0.05$ with a cluster extent threshold of 62 voxels or more¹.

Since vocabulary score was the main predictor in our multiple regression model, we wanted to make sure that there were no confounding factors, like gender or task performance, that could explain our results. It is possible that task difficulty could explain the results; however, it is only intuitive that there will be a significant correlation between vocabulary score and the learner's ability to classify sublexical features of sign language. If vocabulary score and task performance are correlated then following common procedures for dealing with collinearity in predictor variables, one will be excluded. In this case, we will exclude task performance because it does not directly address the current aims. If they are not correlated, then vocabulary will remain within the model.

Previous studies have also shown that women are better at acquiring second languages than men (van der Slik et al., 2015). Therefore, we also analyzed whether our vocabulary scores differed based on gender using a point-biserial correlation at each time point

¹ These clusters happened to also pass family-wise error (FWE) $p < 0.05$ cluster correction implemented in SPM8.

separately². If there is a significant correlation with gender, then parameter estimates of the BOLD signal will be extracted from the significant clusters in our whole brain analysis by defining a 5-mm³ sphere at the center-of-mass for each significant cluster using Marsbar, an SPM toolbox (Baker et al., 2002). Parameter estimates will be correlated with vocabulary scores while controlling for gender in an ad-hoc partial correlation. Only the clusters that survive the gender-correction will be considered significant in our analyses. This method allows us to control for confounding factors while maintaining the integrity of our whole brain analysis.

Results

Correlations

Task performance on the in-scanner phoneme categorization task was arcsine transformed and correlated with vocabulary score and gender at T0 and T2 separately. The analysis revealed trending or significant correlations between vocabulary score and performance at both T0 ($r = 0.563$, $p = 0.057$) and T2 ($r = 0.989$, $p < 0.001$). However, there was no significant effect of gender on task performance at either T0 ($r = 0.083$, $p = 0.797$) or T2 ($r = -0.486$, $p = 0.055$).

Point-biserial correlations between T0 vocabulary score and gender showed moderate negative correlation ($r = -0.541$) that was trending

² Vocabulary scores were also compared between genders using a Wilcoxon rank-sum test, which corroborated the results from the correlation analysis (T0: $Z = -1.8$, $p = 0.072$; T2: $Z = -2.2$, $p = 0.028$).

towards significance ($p = 0.070$), which means that those participants who reported as female tended to have higher vocabulary scores than those who reported as male. Similar correlations between T2 vocabulary and gender revealed a significant negative correlation ($r = -0.714$, $p = 0.009$).

These results revealed that phoneme categorization and vocabulary knowledge are significant correlated, especially after one year of sign language instruction; however, no correction for task performance will be used since they are adversely collinear and statistically represent the same amount of variability. On the other hand, gender did significantly influence vocabulary scores, where female learners outperformed male learners. As such, activation from significant clusters in our whole-brain multiple linear regression will be corrected for gender in our ad-hoc analysis.

Multiple Linear Regression

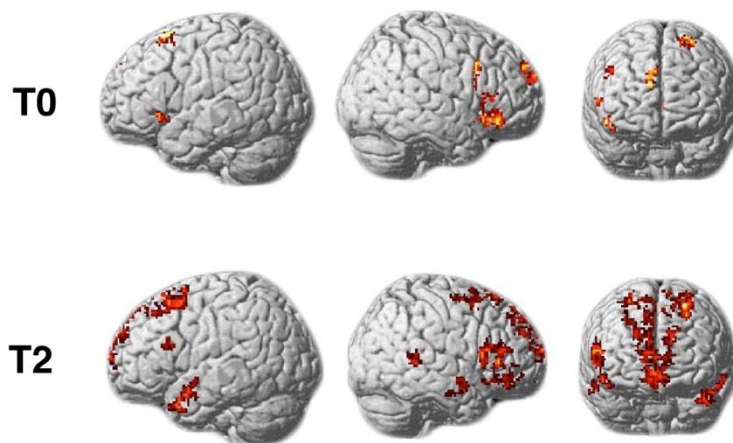


Figure 5 shows activation negatively correlated with vocabulary scores at baseline (T0) and at the second post-exposure scan (T2). Therefore, activation seen here is representative of increased activation to viewing ASL signs for those with poor vocabulary knowledge.

Table 4. Multiple regression analysis (p -corrected < 0.05 ; $k = 62$)

Cerebral Regions	Voxels	MNI coordinates			r	r_{corr}
		x	y	z		
T0						
<i>Left</i>						
Anterior Cingulate Cortex (ACC)	74	-4	34	-2	-0.603**	-0.461†
Insular Cortex (INS), extending into IFG	71	-36	22	-4	-0.855***	-0.787***
Middle Frontal Gyrus (MFG)	85	-26	20	62	-0.741**	-0.614*
<i>Right</i>						
Inferior Frontal Gyrus (IFG)	238	36	24	-14	-0.791***	-0.719***
Anterior Superior Frontal Gyrus (aSFG)	105	12	64	24	-0.653**	-0.445†
T2						
<i>Left</i>						
Inferior Frontal Gyrus (P.Tri)	63	-38	24	22	-0.822***	-0.585*
Supplementary Motor Area (SMA)	226	-8	0	60	-0.906***	-0.797***
Temporal Pole	21	-42	12	-26	-0.865***	-0.747**
Superior Frontal Gyrus (SFG)	117	-16	60	3	-0.823***	-0.609*
Middle Frontal Gyrus (MFG)	373	-24	16	58	-0.854***	-0.745**
<i>Right</i>						
Temporoparietal Junction (pSTC)	66	60	-42	4	-0.845***	-0.653*
Middle Temporal Gyrus (MTG)	75	54	-6	-10	-0.823***	-0.609*

Inferior Frontal Gyrus	125	52	38	-10	-0.739**	-0.463†
Anterior Middle Frontal Gyrus (aMFG)	935	10	48	50	-0.804***	-0.708**
Middle Frontal Gyrus (MFG)	131	26	8	50	-0.783***	-0.556*

Note: † $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 5 shows the increased activation in response to viewing ASL signs that is correlated with poor vocabulary knowledge. Results from the multiple regression analysis indicated a negative correlation such that subjects with lower sign vocabulary knowledge at baseline (T0) had a significant increase in activation in bilateral inferior frontal gyrus, left insula, and left middle frontal gyrus. All of these survived correction for gender differences in vocabulary knowledge. There was also increased activation in left anterior cingulate gyrus and the right anterior portion of the superior frontal gyrus; however, these clusters only trended towards significance once gender was controlled. There were no significant positive correlations with vocabulary score. In other words, there were not any regions that showed increased activation to viewing ASL signs that were positively correlated with vocabulary knowledge.

Results from the multiple regression analysis at T2 showed that there were significant negative correlations in bilateral prefrontal cortex (including superior frontal, middle frontal, and inferior frontal gyri), the right posterior temporoparietal junction (around the superior temporal cortex), the right middle temporal gyrus and the left temporal pole. All of these correlations survived correction for gender except for the right inferior

frontal gyrus, only trended towards significance. There were no significant positive correlations with vocabulary score at T2.

Discussion

The overall objective of the present longitudinal study was to broadly capture how second language (L2) signed vocabulary knowledge affects neural activation during the processing of ASL. Specifically, there were three main research aims. First, we wanted to characterize vocabulary acquisition over two semesters of instruction. Second, given that these learners had little knowledge of sign language at the start of their L2 instruction, one aim was to characterize how limited vocabulary knowledge affects processing of a novel second language. The last aim was to characterize how vocabulary knowledge affects neural processing after 10 months of L2 instruction; specifically, we were interested in how vocabulary knowledge modulated the difference in ASL processing at T0 and after two semesters of instruction (T2) in order to capture potentially diagnostic neurocognitive profiles of learners who struggle with acquiring sign. The results from the present study indicated that poor ASL vocabulary knowledge was associated with increased activation in regions that are commonly involved in lexico-semantic and phonological processing and decision making as well as modality-specific processing of multimodal integration, salience and biological motion processing. This pattern fits into our overall theoretical framework that nonnative signers

struggle with visuomotoric properties, namely movement, that impede their ability to acquire sign language.

In order to characterize how very limited knowledge may impact vocabulary acquisition and processing, ASL learners who had relatively little knowledge of ASL at the beginning of L2 instruction were studied. Despite their limited knowledge after a few hours of instructions at T0, these learners varied in their lexicon size, even at T0 (indicate range). It was hypothesized that learners with poor incoming vocabulary knowledge would show greater activation in regions associated with modality-specific visuomotoric phonetic processing and, perhaps, lexico-semantic processing for known signs that are phonologically related to the target sign (neighbors). The pattern of results from baseline measurements (T0) confirmed our predictions, where increased activation in bilateral inferior frontal gyrus (IFG), left insula and anterior cingulate cortex (ACC), left middle frontal gyrus, and the anterior portion of the right superior frontal gyrus was observed. We will speculate on the role of each activated region in turn.

The left anterior insula has been implicated in language processing (Ardila, Benson, & Flynn, 2007). More generally, however, the activation of the left anterior insula may be more indicative of increased difficulty in cross-modal multisensory integration (Allen et al., 2008; Kurth et al., 2010). Allen and colleagues argue that the insula's connectivity to sensory cortices lends itself to multisensory integration, especially for sign

language which requires visual-tactile-vestibular integration. Similarly, co-activation of the frontoinsula cortex and the ACC point to increased salience processing (Seeley et al., 2007; Uddin, 2015), where the insula is thought to be important for interoceptive and visceromotor body processing. The neural signal from frontoinsula cortex flows to the central executive network, including the ACC, which initiates decision-making (Uddin, 2015). High levels of activation in the anterior cingulate and other prefrontal regions suggests that these learners also required greater effort in areas of decision making and control (Allman et al., 2001; Cohen et al., 2000; Sohn et al., 2007) and perhaps the need to cope with greater task demands (Burgess et al., 2007). As such, it can be hypothesized that learners with smaller vocabulary sizes require more neural resources in order to integrate the visual and motoric salience of the signs so that the phonological content can be determined; therefore, poor vocabulary knowledge is likely linked to less efficient visuomotor phonetic perception, which requires greater neural resources.

Support for poor visuomotor phonetic perception is indicated by the distributed activation in the frontal lobe. The anterior portion of the superior frontal gyrus has been implicated in pseudosign recognition in hearing nonnative signers (Emmorey & Braun, 2011). Additionally, activation in the middle frontal gyrus corresponds to spatial judgements and perspective-taking (Kaiser et al., 2008; Smith et al., 2010) and activation in bilateral inferior frontal gyri are implicated in movement

imitation (Corina & Knapp, 2006; Newman-Norlund et al., 2007). Particularly, **left IFG** has also been implicated in phonological processing of the hand in sign language (Corina, 1999).

Together, these findings suggest that sign language learners with poorer vocabulary knowledge, and perhaps less exposure to sign language, require greater activation in regions involved in multimodal integration, salience, visuospatial and motor phonological processing, and decision making. This pattern of activation might be a predictor of M2L2 deficits in vocabulary acquisition later down the line. This predictive power must be tested in future experiments, but we can evaluate its potential validity by examining activation after one year of exposure.

After two semesters of L2 instruction, or about 10 months, there was a significant increase in the learners' vocabulary scores. Now that learners had more experience with sign language, the study aimed to investigate whether there was a change in the neural substrates recruited for those learners with poor vocabulary knowledge. In fact, the overall pattern of activation was similar at T2 insofar as we observed recruitment of prefrontal and frontal cortex. This means that learners with poor vocabulary scores, even after 10 months of exposure, required greater neural resources when viewing ASL signs. Particularly, the **left IFG** was activated. **Left IFG** has been implicated in the selection of semantic information, where increased activation is representative of more effortful processing and increased difficulty in selection among competing

information (Fiez, 1997; Sakai, 2005; Thompson-Schill et al., 1997; Vigneau et al., 2006). Right IFG has also been shown to be activated during word retrieval when more processing is needed, including bilinguals (Blasi et al., 2002; Marian et al., 2003, 2007). Previous studies on L2 vocabulary acquisition have also shown increased grey matter volume in **left IFG** for high proficiency learners, suggesting more controlled automatic lexical processing (Stein et al., 2012). Increased functional activation was seen in IFG for low-proficiency learners relative to high proficiency learners (Ishikawa & Wei, 2009). There was also differential activation at T2 in the temporal lobes. For instance, there was additional bilateral temporal lobe activation. Left anterior temporal pole activation has also been shown to be involved in the semantic network (Price, 2010). As such, it can be argued that there was greater recruitment needed for word retrieval for these learners with poor vocabulary knowledge. Greater word retrieval difficulties may be due to poor phonological processing more generally.

There is a consistent relationship between L2 phonological processing skills and vocabulary acquisition in spoken languages (Bundgaard-Nielsen, Best, Koors, & Tyler, 2012; Bundgaard-Nielsen, Best, & Tyler, 2011a,b; Darcy, Park, & Yang, 2015). In other words, previous studies have shown that L2 learners' vocabulary size expands as a function of being able to make phonological contrasts in their L2. Given this relationship, it can be hypothesized that the aforementioned deficits in

the M2L2 population might be tied to poor phonological processing, especially given the activation in left IFG. Studies of both spoken and signed language that have shown left IFG is related to phonological processing (Corina et al., 1999; Corina & Knapp, 2006; Emmorey, 2015; Heim et al., 2009; Vigneau et al., 2006; Williams et al., 2015b). For example, Corina and colleagues (1999) found that left inferior frontal areas are important for recognition of bracheomaneal articulation of signs. Moreover, Emmorey and colleagues (2015) similarly found that left IFG is important for complex manual movements. Activation in the supplementary motor area suggest potential motor simulation for bimanual coordination and movement sequence timing (Serrien et al., 2002; Shima & Tanji, 1998). Therefore, after more experience with signs, those learners who have poor vocabulary knowledge also required greater phonological activation when viewing ASL signs. This may be a result of poor modality-specific (i.e., hand and motion) processing that subserves sign language phonology contrasts.

Right hemispheric recruitment of the cortex surrounding temporoparietal junction has been implicated in hand processing and biological motion (see Puce & Perrett, 2003 for a review). Such an activation pattern may indicate difficulty in acquisition of a visual phonology. Difficulty to acquire visual phonology has been reported several times in L2 learners of sign language (Bochner et al., 2011; Grosvald, Lachaud, & Corina, 2012; Morford et al., 2008; Morford &

Carlson, 2011; Chen Pichler, 2011; Rosen, 2012; Schlehofer & Tyler, 2016; Williams & Newman, 2015a, 2016a). Behavioral data has shown that L2 learners of sign language often have more difficulty in processing the handshape and movement phonological parameters relative to other parameters (Bochner et al., 2011; Morford & Carlson, 2011; Williams & Newman, 2015, 2016). Movement is important for sign acquisition because the phonological sequencing of the syllable (i.e., sonority) is directly related to movement, which is the syllable nucleus (e.g., Brentari, 1998). Therefore, poor inability to process the visuomotor phonetic properties of signs, particularly movement, hinder the construction of legal syllable structure, potentially preventing consolidation into or the retrieval from lexical memory. Here, we may have some of the first neural evidence that difficulty with biological motion processing, as indicated by increased activation, which underlies the phonetic and phonological foundation of a visual language, might contribute to poor sign language vocabulary acquisition.

Taken together, the results of the present study revealed that second language learners require activation of modality-independent neural substrates for lexico-semantic processing, such as the inferior frontal gyrus and temporal pole. Additionally, the results from the present study indicated that L2 learners of sign language require automatized processing in areas involved in multimodal integration, salience, biological motion processing and motor simulation. This is the first longitudinal

neuroimaging study that have investigated modality-independent and – dependent mechanisms for second language acquisition of sign language. Therefore, this study provides additional *neural* evidence that second language sign language proficiency (via lexical knowledge) rests on the ability to acquire and process visual phonology. It should be noted that the present study was conducted on a small sample of 12 learners, despite their relative representation of a larger group of learners. Future studies will need to be conducted to examine whether this is a reliable effect and whether these profiles are truly diagnostic of future, perhaps long-term, deficits in M2L2 acquisition, and whether targeted, explicit phonological instruction (pronunciation and perception training) could facilitate M2L2 lexical acquisition.

Chapter 4: Movement Effects on Learning I: Movement Deficits

This chapter has been previously published, but the formatting has been slightly modified for the purposes of this dissertation:

Williams, J.T., & Newman, S.D. (in press). Phonological substitution errors in L1 ASL sentence processing by hearing M2L2 learners. *Second Language Research*, 32(3), 347-366.

Introduction

Second language learners often have difficulty in perceiving and producing phonological contrasts in their second language (Best & Tyler, 2007; Flege, 1995; MacKain, Best, & Strange, 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 (Bochner, Christie, Hauser, & Searls, 2011; Morford et al., 2008; Morford & Carlson, 2011; inter alia). 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.

American Sign Language is the primary language of d/Deaf³ and hard-of-hearing individuals in the United States. ASL is a natural language with all of the same linguistic characteristics of spoken language (e.g., phonology, morphology, syntax, semantics; Sandler & Lillo-Martin, 2006). ASL phonology includes at least three sublexical features: handshape, movement, and location (see Figure 1 for the sublexical characteristics of

³ 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.

the sign CHEESE⁴, Liddell & Johnson, 1989; Sandler, 1989; Brentari, 1998). 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 6). 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 & Carlson, 2011), only handshape, movement, and location will be analyzed in this study.

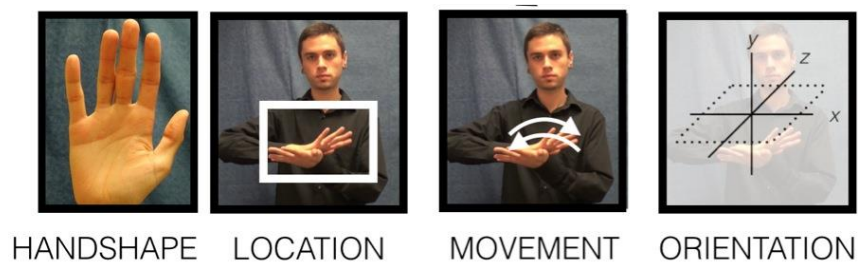


Figure 6 shows the different phonological parameters in American Sign Language.

⁴ Small lower-case letters is the convention for glossing ASL signs.

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 & 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 (Grosvald, Lachaud, & Corina, 2012; Morford & Carlson, 2011; Chen Pichler, 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 nonnative 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 & 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 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 & Bradlow, 2003; Xie & 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 & 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; Mirus, Rathmann, & Meier, 2001; Pichler, 2011; Rosen, 2004). 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, Loucks, Quinto-Pozos, & Dye, 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 & 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 & Rummel, 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 has been seen in ASL sentence recall as well. Native signers are often unable to recognize phonological mismatches (Hanson & Bellugi, 1982) and nonnative signers make many phonological errors in sentence recall (Mayberry & 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 & Marian, 2012, Van Hell, Ormel, Van der Loop, & Hermans, 2009; Williams & Newman, 2015). In fact, Williams & 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 & 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 (Maybery & 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.

Research Questions

The current study investigates intelligibility effects of native versus M2L2 signer status in the perception of ASL by M2L2 learners. The primary 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?

Method

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. 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.

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 (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 & Newman, 2015). Additionally, self-reported fingerspelling has been shown to be correlated with ASL proficiency in native signers (Mayberry & Eichen, 1991). Participants saw a series of seventy 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:

$$P = \frac{\left(\frac{\text{FRT}}{70}\right) + \left(\frac{\text{Self-Rating}}{7}\right)}{2}$$

The proficiency scores range from 0 to 1. A composite of 0 indicates a naïve 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 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 & 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 (MacIntyre, Noels, and Clement, 1997; Bachman and Palmer, 1989). 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.

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.

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 (~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 IX_{pro.1p} ('I'), MISS, CANDY, and SOMETIMES share the same handshape. Additionally, the signs MISS and 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., *cat*, *ate*, *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 subject. 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 ($F_{(1,39)} = 88.620, p < 0.001, \eta^2 = 0.823$), 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, $F < 1$.

Procedure

Participants were seated in front of a 27-inch iMac. Stimulus presentation was controlled by *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 & Fowler, 2013; Bent & Bradlow, 2003). The ability to transcribe the stimuli in ASL is limited, as there is no official orthographic system in ASL. Therefore, subjects 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 analyzed 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 7). 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.

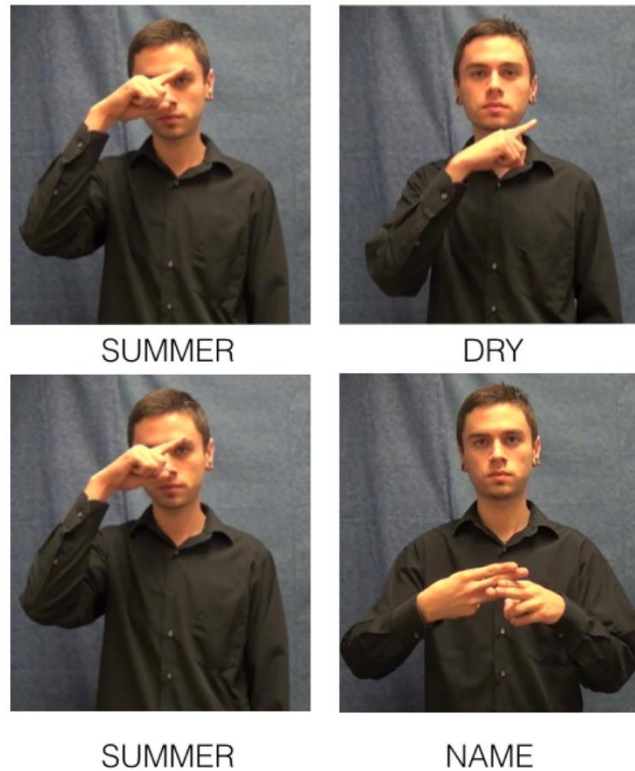


Figure 7 illustrates a minimal pair contrast (top; SUMMER vs. DRY) that would constitute a phonological substitution error in the present study. The minimal pair is contrasted with an unrelated lexical error (bottom).

Results

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 performed⁵. The main effect of signer was not significant [$F(1,20) = 1.287, p = 0.370, \eta^2 = 0.060$]. The learners

⁵ 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.

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.

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 [$F(2,40) = 5.088$, $p < 0.05$, η^2

= 0.203] were significant. The main effect of parameter (see Figure 8) 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%).

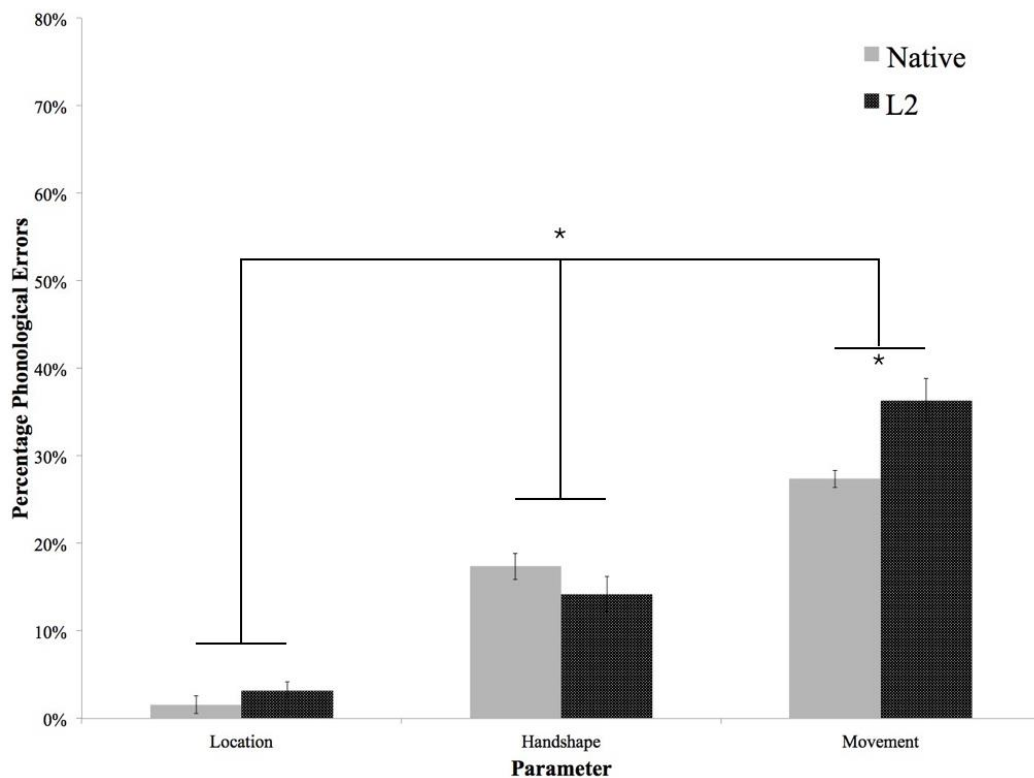


Figure 8 illustrates the proportion of phonological errors (in percent) for each phonological parameter and by signer status (native versus L2 signer).

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-analyzed 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.

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 analyzed 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.

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 & 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 & Carson, 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 & 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 & 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.

Interlanguage intelligibility benefit

Second language learners often have gains in intelligibility compared to native speakers when listening to other nonnative talkers (Bent & Bradlow, 2003; Xie & 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., Best & Tyler, 2007; Flege, Schirru, & MacKay, 2003; Flege, 1995; Kuhl & Iverson, 1995; Strange, 1995). 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.

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 & 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 & Pisoni, 1998). Signs have been shown to cluster in dense neighborhoods based on the handshape feature (Caselli & Cohen-Goldberg, 2014; Carreiras, Guiterrez-Sigut, Baquero, & Corina, 2008). Increased activation of phonological neighbors often results in more errors in spoken language recognition tasks (Vitevitch, 2002; Vitevitch & 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, persistent 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 & 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.

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, visuo-phonetic 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 (Trieman & Hirsik-Pasek, 1983) as well as recall of a list of signs (Wilson & 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 & 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, Chincotta, Stafford, & Turk, 2003; Fallon, Groves, & Tehan, 1999; Gathercole, Frankish, Pinkering, & Peaker, 1999; Loble, Baddeley, & Gathercole, 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.

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.

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.

Chapter 5: Movement Effects on Learning II: Sonority

This chapter has been previously published, but the formatting has been slightly modified for the purposes of this dissertation:

Williams, J.T., & Newman, S.D. (2016). Impacts of visual sonority and handshape markedness on second language learning of American Sign Language. *Journal of Deaf Studies and Deaf Education*, 21(2), 171-186. doi: 10.1093/deafed/env055

Introduction

Learning a new language late in adulthood can be a difficult experience. Learning novel sounds (Best & Tyler, 2007), word segmentation (Field, 2003), and a myriad of other features (Birdsong, 1992) can create many roadblocks along a learner's acquisition path. However, there are many characteristics of the first language that can facilitate acquisition of a second language (Gass & Selinker, 1992). Many of the phenomena that have been documented to either facilitate or hinder second language acquisition are largely restricted to our knowledge of how two spoken languages interact within a bilingual system. Learners whose first and second languages are both spoken are referred to as *unimodal* bilinguals. On the other hand, those learners whose first language is spoken but are acquiring a sign language are referred to as *bimodal* bilinguals. A distinction between the types of language modalities that bilinguals use is important to our understanding of how knowledge of one language can influence the acquisition of another. Most studies that examine transfer effects investigate two spoken languages. One could imagine how general knowledge of the universal structure of phonology (e.g., sonority) could influence sign language acquisition, however, regardless of the divergence between the two language modalities.

Evidence for amodal transfer between languages during L2 acquisition comes from studies that have demonstrated that learners of a sign language use knowledge of their first language co-speech gesture

system (Brentari, Nadolskey, & Woldford, 2012; Chen Pichler, 2009) as well as other sources (Chen Pichler & Koulidobrova, to appear) to aid in sign language acquisition. As such, it is likely the case that bimodal bilinguals can use such knowledge to help attune to salient features in their sign language. It has been hypothesized that there are modality-independent phonological characteristics of language (Berent, Dupuis, & Brentari, 2013). In fact, sonority, or the perceptual salience of a phonetic feature, has been implicated as an amodal feature that is pervasive in both spoken and sign languages. It is possible that sonority can also be processed at the perceptual level regardless of L1 phonological knowledge. As such, the present study aims to investigate the role of visual salience on sign language learning in hearing adults.

Multidimensional perceptual salience, or the ability for a feature to stand out in the input based on some dimension, has been shown to be important during many cognitive processes, including language acquisition (Goldschneider & Dekeyser, 2001; Yantis & Egeth, 1999). Multidimensional salience in language can arise in what is termed sonority (Ohala and Kawasaki, 1984). Sonority in spoken language has a phonetic correlate of amplitude, or loudness, of a given speech sound. In other words, sonority is often thought of as the relative degree of constriction of the oral cavity (Chin, 1996). In fact, sonority can be ranked on a hierarchy based on its relative amplitude (Hankamer & Aissen, 1974). In addition to having phonetic correlates, sonority can also be important phonologically.

For instance, sonority is important in the syllabification of languages insofar as languages often arrange their sound sequences based on constraints of sonority (see *Sonority Sequencing Principle*, Clements, 1990). As such, the syllable and its sonority have representational power within the phonological system of any given language (Blevins, 1995). The representational power of the syllable (i.e., sonority) in spoken language can affect child language acquisition and unimodal second language acquisition. Children are aware of sonority restrictions early in acquisition (Berent, Harder, & Lennertz, 2011) and attune to speech as a function of sonority (Yavas & Gogate, 1999). Children also produce sound clusters with the greatest sonority rise earlier (Ohala, 1999) and show greater generalizability of learning patterns based on sonority complexity (Gierut, 1999). Additionally, unimodal second language (L2) learners show increased variability in L2 production as a function of sonority (Broselow & Finer, 1991; Eckman & Iverson, 1993; Tropic, 1987). It is important to investigate whether sonority impacts sign language learning given positive evidence that sonority may impact spoken language processing and learning; however, we must first explicate how sonority is defined in sign languages.

Based on the fact that sonority is the conceptual representation of perceptual salience in language, it is unsurprising that sign languages also have a visual correlate (Brentari, 1998). Sign phonologists agree that movement is the most sonorous element in a well-formed sign (Brentari,

1998; Corina, 1996; Perlmutter, 1993; Sandler, 1993; Wilbur, 1993). Signs have similar syllable structure as spoken words insofar as movement accounts for the syllable nucleus, similar to vowels (Brentari, 1998, 2002; Sandler, 1993). However, there is some debate as to how best to quantify sonority. For instance, visual sonority can be derived from the proximity of the articulating joint (e.g., shoulder, elbow, fingers, etc.; Brentari, 1998), the type of movement during a sign's production (Sandler, 1993), or by other perceptual variation like movement size (Crasborn, 2001). On the other hand, sonority has also been posited to be derived based on phonotactics and movement deletion patterns, which are separable from the aforementioned theories of movement-type sonority (Corina, 1996). These accounts differ based on whether sonority is treated as phonetic or phonological in nature, respectively. For instance, the sonority hierarchy proposed in Sandler (1993) is purely phonetic given that not all contrasts based on movement characteristics are phonologically motivated (see Corina, 1996 for discussion). Although theories of sonority in sign languages, like spoken language, are complex and still unresolved, the present study adopts the stance that sonority can be phonetic in nature and thus movement characteristics (e.g., articulating joint, path and hand-internal movements, etc.) are important to the perceptual salience of the sign (see Brentari, 1998; Sandler, 1993).

According to the particular theory adapted in this study, movements distinguish the syllable complexity and are the most sonorous elements of

the sign. Thus, sign languages can create sonority by the perceptual visibility of the articulating joint (e.g., signs with shoulder movements are more visible than those with interphalangeal movements; Brentari, 1998, pg. 217). It could be assumed based on this account of sonority that greater visibility, which implies greater sonority, could provide advantages for some signs over others in terms of identification and subsequent processing. Motion (or movement) has been shown to enhance visual perception in other domains (e.g., Ambadar, Schooler, & Cohn, 2005). As such, the same may apply to sign language learning. In fact, many studies have shown that native deaf signers and second language learners of sign language often acquire and identify movement features much later and with more errors than the other phonological parameters (Bochner et al., 2011). Moreover, deaf children often use less motorically complex proximal articulators (i.e., shoulder; high sonority) than the complex adult-target distal articulators (i.e., phalangeal joints; low sonority) during early sign language acquisition (Meier, 2006, 2008). Studies have yet to examine the role of sonority on movement identification or production in adult learners. Due to the perceptibility of high sonority signs and the fact that hearing second language learners have fully developed motor systems, it is possible the high sonority signs may be acquired more easily.

It should be noted that perceptual salience in sign language may not be restricted to movement sonority. Based on a number of studies,

there is evidence that learners may have difficulty in the perception of other sublexical features (or parameters) based on their perceptual salience and psycholinguistic properties (Bochner, Christie, Hauser, & Searls, 2011; Emmorey, McCullough, & Brentari, 2003; Grosvald, Lachaud, & Corina, 2012; Morford, Grieve-Smit, MacFarlane, Staley, & Waters, 2008; Morford & Carlson, 2011). It might be the case that the perceptibility of a given sign is a function of multiple features; that is, a combination of a salient handshape and a salient movement (i.e., sonority) might provide greater perceptibility.

Multiple cues can be advantageous in cognitive processing across multiple domains. For instance, multiple auditory cues can aid in auditory processing (Schroger & Widmann, 2003). Furthermore, when listeners are shown visual information in conjunction with auditory information, there is expedited processing both in behavioral performance and neural processing (Du et al., 2011; van Wassenhove, Grant, & Poeppel, 2005). Multiple cues in visual processing are also advantageous (Itti & Koch, 1999). Given that multiple cues aid in cognitive processing across domains, it may be the case that beginner learners of sign language also use multiple perceptual cues (e.g., sonority, handshape markedness) during sign language learning. In order to develop a more nuanced understanding of the interaction between perception and sign language acquisition, it's important to begin moving away from a simplistic conception of sign parameters as a linear hierarchy of features and to

investigate whether it is in fact a dynamic system where multiple features interact to contribute to overall saliency. As such, it is important to examine the role of different types of salience.

Markedness may provide another source of salience. Unmarked features are common features that occur relatively often, whereas marked features are unusual and occur rarely; markedness can be thought of as the relative frequency of a given feature (Jakobson, 1968). Handshape, or the configuration of the selected fingers of a sign, can be delineated into a group of marked and unmarked handshapes. Typically, unmarked handshapes are limited to a small group of handshapes (B, A, S, C, O, 1, and 5; Battison, 1997; Boyes-Braem, 1990, Grosvald et al., 2012; Siedlecki & Bonvillian, 1997; see Appendix for depictions of handshapes). Deaf children acquire unmarked handshapes earlier, which is thought to be a result of motoric simplicity (Ann, 2006; Siedleck & Bonvillian, 1997). This points to another account of markedness such that it is a result of motoric complexity. Ann (2006) computed handshape markedness in Taiwanese Sign Language based on ease of articulation as determined by several anatomical criteria (e.g., muscle opposition in handshape configuration, support for extension and flexion, tendency to oppose thumb and tendency to spread), which roughly, but not exclusively, correlated with many findings in the ASL literature (see Boyes-Braem, 1990). Additionally, given that markedness can be accounted for by either frequency or motoric complexity, and that hearing nonsigners or naïve

learners are not attuned to the frequency characteristics of the language, learners may process markedness based solely on motoric complexity. However, handshape markedness may not be relegated to only motoric complexity, but also visual complexity. In a phoneme-monitoring task, deaf signers perceived marked handshapes better than unmarked handshapes; however, hearing nonsigners perceived unmarked handshapes better (Grosvald et al., 2012). This reversal is thought to be driven by perceptual salience such that deaf signers attune to information that stand out in their input (i.e., marked features), whereas hearing nonsigners attune to less complex structures (i.e., unmarked features). Thus, it might be hypothesized that signs that contain unmarked handshapes would be less complex and be more easily acquired by hearing second language learners. However, it is not clear whether the complexity that drives these differences lies within the visual or motoric systems.

Taking these factors into consideration together with theories of sonority, it was predicted that the acquisition of signs depends on multiple saliency features. It was hypothesized that multiple features and their visual saliency values influence sign language learning. Despite learners perceiving unmarked handshapes better than marked, we predicted that signs that contain marked handshapes and high sonority movements increase perceptibility. This prediction is due to marked handshapes being visually distinctive, especially when paired with high sonority movements. Hence, greater perceptibility of the sign will have an additive effect on the

phonological specification during acquisition. It is possible, however, that unmarked handshapes with high sonority movements are easier to acquire. In that vein, the roles of motoric and visual complexity were investigated by examining the subsequent production of these signs. Since both sonority and handshape markedness can be derived from both motoric and visual complexity, these differential effects of sonority and handshape markedness may change when signers are required to produce these signs. It is hypothesized that marked handshapes with high sonority movements are more easily perceived due to the increase in *visual* salience; it can be conversely hypothesized that signs with high sonority (i.e., high visual salience) and marked handshapes (i.e., high motoric complexity) are harder to produce overall, biasing production to be faster for unmarked handshapes (see the influence of articulatory complexity on speech sound and lexical acquisition in children: Cairns, 1996; Sander, 1972; Schwartz & Leonard, 1982). We hypothesized that the benefits of certain salient features (i.e., sonority, handshape markedness) play differential roles in perception and production during the acquisition process.

To summarize, this study aimed to explore the role of visual salience (i.e., sonority and markedness) on the perception and production of ASL. We tested these hypotheses using a sign-picture matching paradigm in Experiment 1 and tested a subsequent reproduction task using a key-release measure in Experiment 2. A sign-picture matching

task was chosen because previous studies have used the method effectively to investigate how certain linguistic aspects influence both child language and adult second language learning (Escudero, Hayes-Harb, & Mitterer, 2008; Showalter & Hayes-Harb, 2013; Storkel & Adlof, 2009; Storkel & Lee, 2011). Given that we were interested in how sonority and handshape markedness influence sign acquisition in adult learners this task is quite useful because we are able to explicitly test learners' accuracy in acquiring a sign across these conditions. Additionally, the sign learning task provided a method to explicitly test how these features influence recognition (or encoding). On the other hand, a sign reproduction task was chosen to test whether sonority and markedness would differentially affect production. A distinction between these two processes provides insights into how salient phonological features influence encoding and retrieval differentially and whether sonority and markedness are more visually or motorically salient.

Experiment 1: Sign-Picture Matching Task

Methods

Participants. Twenty-five English-speaking participants (4 male) were recruited from an introductory psychology course. All participants received course credit for their participation. The university Internal Review Board approved all procedures. The participants' ages ranged from 18 to 21 years ($M = 18.32$; $SD = 0.69$). All participants scored as right-handed on

the Edinburgh Handedness Inventory (Oldfield, 1971; $M = 72.5$; $SD = 16.1$). Eighteen participants reported at least one spoken second language (Spanish = 12; Japanese = 2; Latin = 1; German = 1; Tamil = 1; Hindi = 1), but no participants reported experience or exposure to any sign language (including American Sign Language). Additionally, all participants reported no speech, hearing, or neurological disorders. Hearing nonsigners were selected for this study in order to simulate initial stages of learning. This also allowed us to make conclusions based on the perceptual processing of signs with no interaction with established lexical items.

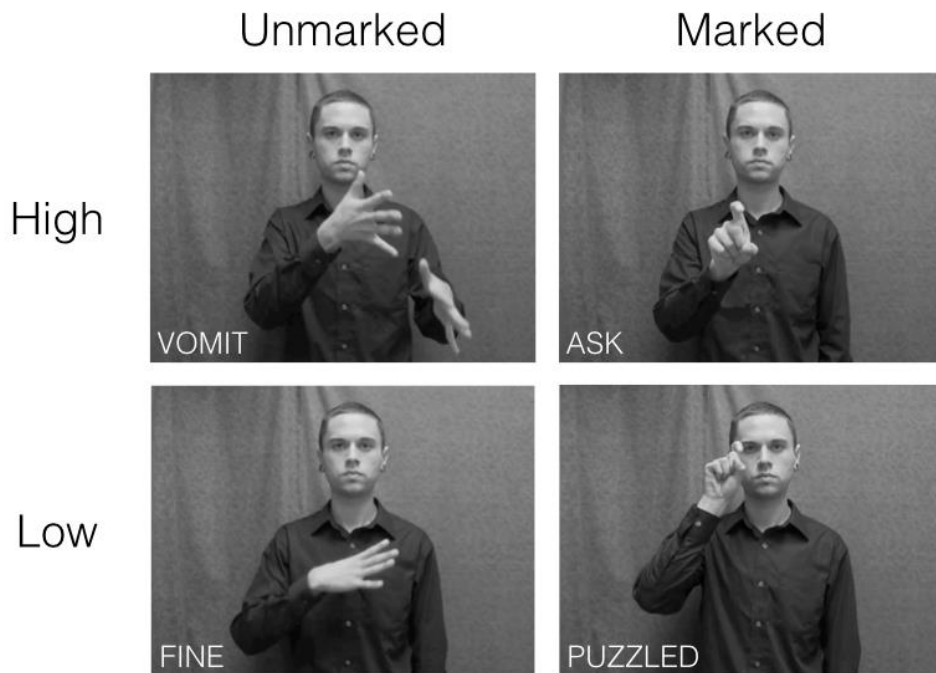


Figure 9 displays a sample of the stimuli included in this experiment. Signs with high sonority are on the top row (e.g., VOMIT, ASK) and those with low

sonority on the bottom row (e.g., FINE, PUZZLED). As static 2D pictures it is hard to intuitively derive the sonority; however, the high sonority signs are characterized by path movements that span the neutral space (e.g., vomit: mouth to neutral; ask: mouth to neutral). The low sonority signs have either internal handshape movements (e.g., PUZZLED is stationary at the forehead but the handshape changes from 1 to X) or local movements (e.g., FINE: slight repeated taps to the chest). The stimuli are further delineated by markedness across columns, with signs with unmarked handshapes (e.g., B) to the left and marked handshapes (e.g., X) to the right. Photo released with permission.

Materials. Sixteen to-be-learned ASL signs were selected. These sixteen signs were split into high and low sonority groups ($n = 8$ each). Sonority was rated using both the Brentari (1998) and Sandler (1989) models of ASL sonority scales. Based on these models a general sonority hierarchy was constructed for this study in which sonority was determined by a combination of articulating joint (i.e., shoulder (5) > elbow > wrist > base > nonbase (1)) and movement type (i.e., path movements with trilled internal movements (5) > path movements with internal movements > local internal movements > contacting movements > trilled stationary (1)). For example, a sign that is articulated with the shoulder joint with a trilled path movement would theoretically be the most sonorous and a sign that is articulated with base and nonbase joints with a trilled stationary movement

would be least sonorous. The group of high sonority signs included COMMUNICATION, VOMIT, SHOW, SORRY, DECIDE, JOIN, ASK, and SYMPATHIZE. The low sonority signs included COOKIE, FINE, HUH, AUDIOLOGY, HIGH-SCHOOL, PUZZLED, and HATE (refer to Figure 9 for a sample of the stimuli). There was a significant difference of sonority ranking between the low and high sonority groups [$t(7) = 4.710$, $p < 0.05$; high = 4.25 (0.46), low = 2.38 (0.74)]. In order to capture other possible explanations of visual saliency, signs in both low and high sonority groups were split into two subsequent groups based on handshape markedness. Markedness was based on several studies that have documented the acquisition of handshape by children and adults (Ann, 2006; Boyes-Braem, 1990; Brentari, 1998; Grosvald et al., 2012; Siedlecki & Bonvillian, 1997). Signs were classified as unmarked if they contained the unmarked handshapes B, A, C, 1, and as marked if they contained the marked handshapes F, H, X, or 8 (see Appendix for depictions of handshapes). A native ASL signer signed the stimuli at a slow but naturalistic rate in front of a blue-gray backdrop. Video clips of the signs were edited to one frame before lift of the hands and one frame after the drop of the hands. The durations of the signs did not differ across sonority [high = 1663 (171) ms; low = 1538 (207) ms; $F < 1$], markedness [unmarked = 1600 (184) ms; marked = 1600 (143) ms; $F < 1$], or an interaction between the two [$F < 1$]. All other aspects of sign phonology (e.g., number of hands, location, etc.) were randomly varied.

All of the signs were paired with a novel nonobject. Sixteen imageable gray scale line drawings of nonobjects were pseudo-randomly selected from Kroll and Potter (1984). Nonobjects were selected such that there was no iconic mapping between the phonology of the sign and the nonobject's representation (see Figure 9 for examples of nonobjects). Iconicity has been shown to influence sign acquisition and processing such that native deaf signers and late L2 learners are often faster at naming highly iconic signs (Ormel, Hermans, Knoors, & Verhoeven, 2009; Thompson, Vinson, Vigliocco, 2009; Thompson, 2011), but the number of arbitrary, noniconic signs that are acquired early in language acquisition outnumber iconic signs (Orlansky & Bonvillian, 1984) and sign acquisition often does not follow iconic principles (Emmorey, 2002; Meier, 1982). Additionally, iconicity does not have a privileged role in lexical access (Bosworth & Emmorey, 2010). Therefore, shielding against iconicity does not invalidate the learning of these signs. Nonobjects were also selected so that participants would be required to create a new semantic representation as well as to shield against imageability between sign and semantic representations. All subjects saw the same sign-nonobject pairs, which is similar to the use of nonobjects in language learning that has been demonstrated in a number of other successful child language learning paradigms (Storkel & Adlof, 2009; Storkel & Lee, 2011) and L2 learning paradigms (Escudero, Hayes-Harb, & Mitterer, 2008; Showalter & Hayes-Harb, 2013).

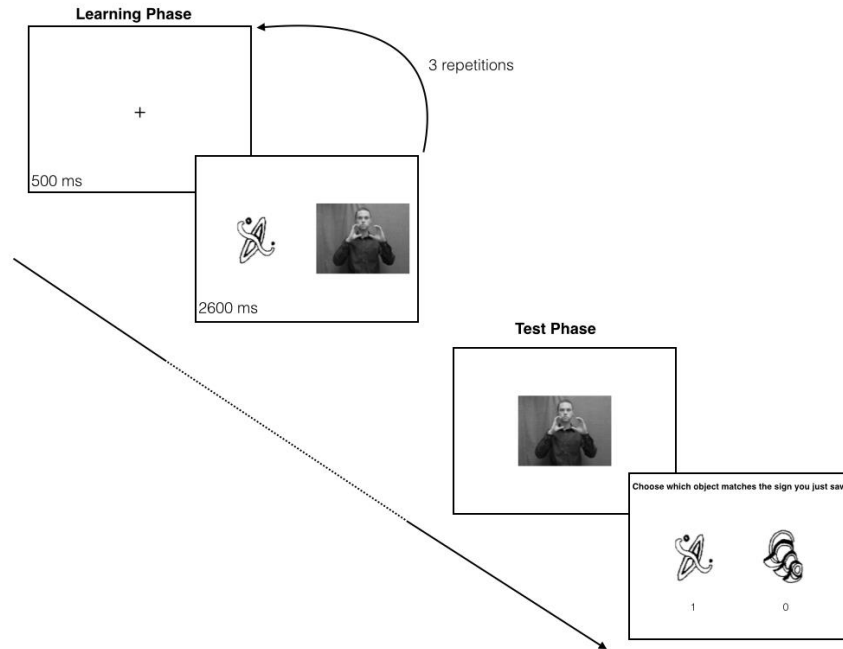


Figure 10. Study design.

Procedure. The procedure used was similar to previous studies examining L2 phonological acquisition (see Showalter & Hayes-Harb, 2013, 2015). Participants were seated at a 27-inch widescreen iMac computer. The experiment was controlled by *PsychoPy* software (Peirce, 2007). There were two phases: the learning phase and the final sign-picture matching test. The participants were presented with a 500-millisecond fixation cross before each trial. During the learning phase participants were exposed to both ASL sign and nonobject representations. The ASL signs were presented on the right side of the screen. To the left of the ASL sign appeared the matching nonobject representation. Previous spoken L2 studies have simultaneously presented the word aurally and the semantic representations visually in a cross-modal learning paradigm. Since all of

the stimuli in the present study are visual, the ASL sign was presented for the duration of the sign and the nonobject was presented for 1000 milliseconds longer than the sign (e.g., ASK = 1600 ms, nonobject = 2600 ms; see Figure 10). This method of presentation was assumed to provide the participants enough time to visually encode all of the information on the screen. Participants were also instructed to look at the right side of the screen (for ASL sign) first and then look to the left (for the nonobject). Each of the sixteen signs was randomly presented once per block for 3 block repetitions.

The final sign-picture matching test consisted of all sixteen signs randomly presented. Immediately after the presentation of the sign, a two alternative force choice nonobject referent-matching paradigm was presented to the participants. Two nonobjects appeared on the screen. The correct nonobject was randomly assigned to either the left or the right. Another nonobject (that was the correct answer for another sign representation) was randomly presented in the other location. Participants were instructed to select the nonobject that matched the sign they previously had seen. If the correctly matching nonobject was on the left, the participants were to press the '1' key with their left index finger. If the correctly matching nonobject was on the right, the participants were to press the '0' key with their right index finger. All selections were instructed to be as fast as possible, while being as accurate as possible. Reaction times were measured at the onset of the trial. Given that there was no

significant difference in video lengths across all conditions, reaction times should not be colored by video lengths. The test phase only presented each sign once. None of the alternative nonobject choices (the foils) were shown more than once as a foil.

Data Analysis

Data analysis was conducted using mixed-effects models (R Statistics v.3.1.2; Bates et al., 2013) that included both fixed effects (i.e., sonority and markedness) and random effects (i.e., participants and items). Mixed-effect modeling is now commonplace in psycholinguistic literature in light of many arguments against traditional analysis of variance. Specifically, mixed-effects models allow for the modeling of random effects that are caused by participant and item variance. Additionally, mixed-effects models can account for both continuous (e.g., reaction times) and binary outcomes (e.g., accuracy counts; see Baayen, Davidson, & Bates, 2008 and Jaeger, 2008 for discussion). Each model investigated the main effects of the fixed effects (i.e., sonority and markedness) as well as their interaction at both the participant/group ($F1$) and item ($F2$) levels by including these as random effects.

Results

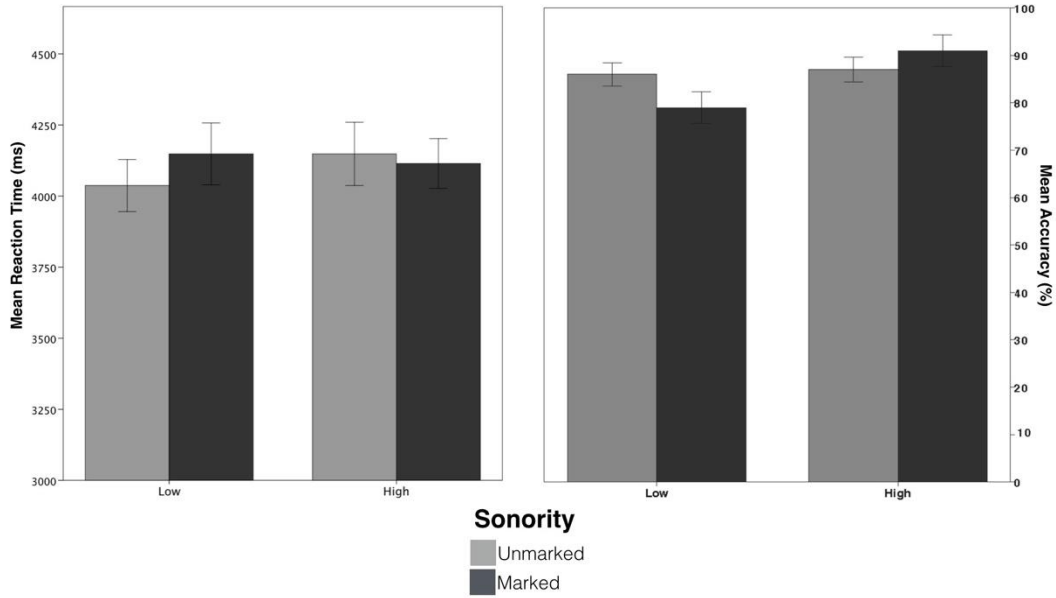


Figure 11 shows the reaction time (in milliseconds; left) and accuracy (right) results for the sign-picture matching task split by sonority and markedness. Error bars represent ± 1 SE.

Table 5. Statistics for Experiment 1 Learning Note: $F1$ = group, $F2$ = item, * = significant

Predictor	Condition		Mean	SE	$F1$ $F2$	$p1$ $p2$
	Sonority	Markedness				
Reaction Times						
Sonority	high		4131	81	0.022 0.003	0.881 0.995
	low		4093	92		
Markedness		unmarked	4093	85	0.626 0.093	0.429 0.764
		marked	4131	90		
Sonority x Markedness*	high	unmarked	4148	111	7.803 1.164	0.005 0.297
		marked	4115	88		
	low	unmarked	4037	92		
		marked	4148	109		
Accuracy						
Sonority*	high		89.0%	2.5	7.592 2.067	0.006 0.170
	low		82.5%	2.5		

Markedness		unmarked	86.5%	2.2	0.404	0.525
		marked	85.0%	2.8	0.110	0.110
Sonority Markedness*	high	unmarked	87.0%	2.6	5.436	0.020
		marked	91.0%	3.3	1.480	0.241
	low	unmarked	86.0%	2.4		
		marked	79.0%	3.4		

Reaction times measured from the onset of correct trials were filtered for outliers that fell two standard deviations above or below the mean (1.4%). Descriptive statistics can be found in *Table 5*. The linear mixed-effects model revealed no significant main effects of either sonority [$F1(1,775) = 0.022, p = 0.881; F2(1,16) = 0.003, p = 0.995$] or markedness [$F1(1,775) = 0.626, p = 0.429; F2(1,16) = 0.093, p = 0.764$]. There was a significant interaction observed between sonority and markedness at the group level [$F1(1,775) = 7.803, p = 0.005; F2(1,16) = 1.164, p = 0.297$].

Accuracy results revealed a significant main effect of sonority at the group level [$F1(1,775) = 7.592, p = 0.006; F2(1,16) = 2.067, p = 0.170$] such that high sonority signs [89% (2.5)] were more accurately learned than low sonority signs [82.5% (2.5)]. There was no main effect of markedness [$F1(1,775) = 0.404, p = 0.525; F2(1,16) = 0.110, p = 0.467$] such that both unmarked [86.5% (2.2)] and marked [85% (2.8)] signs were learned equally well. There was an interaction of sonority and markedness at the group level [$F1(1,775) = 5.436, p = 0.020; F2(1,16) = 1.480, p = 0.241$].

Recall, this study aimed to investigate: 1) whether visual sonority provides greater intelligibility for marked handshapes; and 2) whether there are additive effects of sonority and markedness on learning such that unmarked high sonority (i.e., high salience, low complexity) signs are easier to acquire than marked low sonority signs (i.e., low salience, high complexity). Planned t-tests were performed to investigate these outstanding hypotheses and to further explore the interaction effects in both RTs and accuracy. A comparison of low and high sonority signs that both contained marked handshapes revealed a significant effect only for accuracy [$t(24) = 3.361, p < 0.01$] such that high sonority signs [91.0% (3.3)] were more easily learned than low sonority signs [79.0% (3.4)] when they contained a marked handshape [$t_{RT} < 1$]; however, they did not differ when they contained an unmarked handshape for either RTs or accuracy [$t_s < 1$]. A comparison of unmarked high sonority and marked low sonority signs revealed a significant difference for both RT [$t(24) = 2.144, p < 0.05$] and accuracy [$t(24) = 2.486, p < 0.05$] such that unmarked high sonority signs [87.0% (2.6)] were learned more easily and responded to more quickly [4036 ms (38)] than marked low sonority signs [accuracy: 79% (3.0); RT: 4148 ms (54)]. However, this was not the case for high sonority signs that differed in markedness only? [accuracy: $t(24) = 1.138, p = 0.266$; RT: $t < 1$].

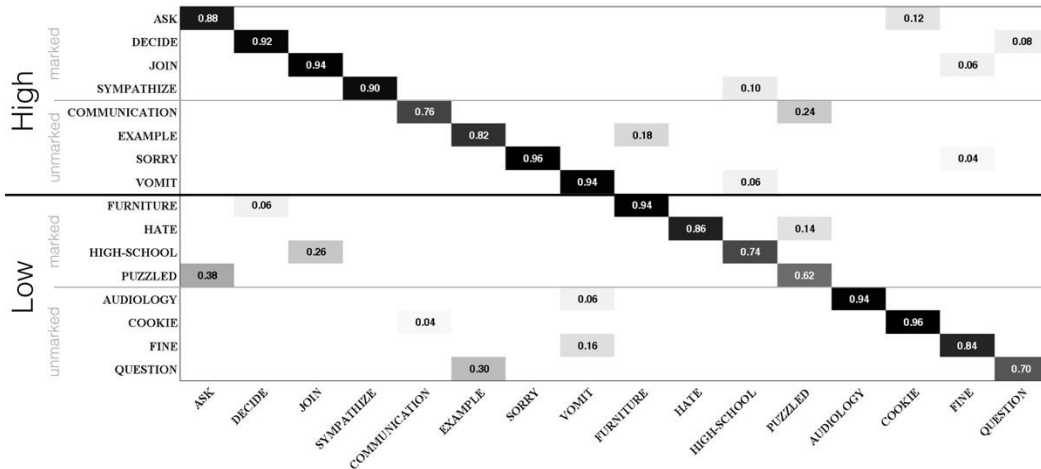


Figure 12. A confusion matrix was constructed to qualitatively characterize the confusions between signs in the learning phase of Experiment 1. The signs are ordered based on their sonority and markedness. The boxes are colored based on how often a sign was identified as that sign, where greater identification with a given sign was weighted by a darker color. The values along the diagonal represent correct identification and other values are misidentifications. Values are proportions (0 to 1) and can be converted to percentages by multiplying by 100. It should be noted that this confusion matrix should be read left to right, with the confusion summing up to 1 (or 100%) across the columns in any given row. For example, ASK was only categorized as either ASK (88%) or COOKIE (12%), but not PUZZLED (0%); however PUZZLED was in fact misidentified as ASK 38% of the time.

Given that the planned comparisons showed a hierarchy of confusability in accuracy (e.g., high+marked (91%) > high+unmarked

(87%) = low+unmarked (86%) > low+marked (79%)), it was important to delineate confusability more explicitly. A confusion matrix was computed in order to capture qualitative insight into how signs were learned based on their sonority and markedness. How often a given sign was classified as another sign in the learning test phase was calculated. In Figure 12, the signs are plotted and divided by their sonority and markedness. Along the diagonal is how often a given sign was correctly identified as itself with the proportion indicated in the box. Here we can qualitatively capture how signs were confused based on their sonority and markedness by summing the confusion value for each sign within a condition and dividing by the number of confused signs. For sonority, results from the confusion matrix revealed that low sonority signs were mistaken for other low sonority signs (14.0%) less often than high sonority signs (18.0%) and high sonority signs are mistaken for other high sonority signs (0%) less often than for low sonority signs (11.0%). Taken together, this suggests that low sonority signs were mistaken for any other sign 16% of the time, whereas high sonority signs were mistaken for any other sign only 5.5% of the time. For markedness, results indicated unmarked signs were mistaken for marked signs (16.0%) more often than for other unmarked signs (12.0%). Marked signs were mistaken for other marked signs (18.8%) more than for other unmarked signs (8.6%). Collectively, this pattern of results indicated that unmarked signs were mistaken for any other signs (14%) only slightly more often than marked signs (13%). A conjunction of the two conditions

indicated a similar hierarchy as mentioned above such that high sonority signs with marked handshape were misidentified only 9.0% of the time relative to high sonority signs with unmarked handshapes (13.0%), low sonority signs with unmarked handshapes (14.0%), and low sonority signs with marked handshapes (21.0%). Given that the confusion matrix demonstrates the predicted inverse relationship to the accuracy data (i.e., the more accurate, the less confusion), then we can confidently say that the same general hierarchical pattern is robust.

Participants attempted to learn novel ASL sign-nonobject mappings in a repetition nonobject referent-mapping task in Experiment 1. It was our aim to investigate the role of visual salience on the acquisition of novel signs. It was hypothesized that high visual sonority would facilitate sign-picture matching. Additionally, the visual salience of marked handshapes was also expected to facilitate acquisition. Thus, it was predicted that to-be-learned signs that contained low sonority movements and unmarked handshapes would be harder to acquire due to their low perceptual salience. The data presented indicated that there were no main effects in reaction time across conditions; however, accuracy results revealed that participants were more successful at matching high sonority signs with their nonobject representations than low sonority signs. This pattern of results may indicate that visual sonority is crucial during sign language learning. It is likely that learners attuned to signs that contain high sonority movements and were better able to encode their phonological features.

Since previous studies have shown that the handshape parameter is often more difficult to acquire for second language learners (Morford & Carlson, 2011) and handshape markedness differentially affects processing (Grosvald et al., 2012), the question of whether the effects of markedness are diminished (or highlighted) with greater visual sonority remained.

It was also found that signs were learned more easily when marked handshapes were embedded in high sonority signs. This advantage was not seen for unmarked handshapes, where signs containing unmarked handshapes in high sonority signs (87%) were matched to those in low sonority signs (86%). The salient feature of a marked handshape likely drew attention to the handshape parameter. Attention directed to a marked handshape was then highlighted by the high visual saliency of the sign to provide distinct features to encode the sign representation (and its phonetic parameters). This interaction between sonority and markedness was further demonstrated by a second comparison of unmarked high sonority and marked low sonority signs, which revealed that participants matched unmarked high sonority signs with their nonobject better than marked low sonority signs. Despite the additive facilitation by high sonority when learning signs with marked handshape, this pattern of results indicates detrimental effects of both low sonority and marked handshapes. These results can be explained by the fact that learners are burdened by marked handshapes in a low visually distinctive signal (i.e., low sonority); whereas, learning is facilitated by high sonority and is not negated by

marked handshapes. This supports previous research that shows that learners have difficulty with handshape identification, discrimination, and learning (Bochner et al., 2011; Morford & Carlson, 2011; Morford et al., 2008), but do better with unmarked handshapes (Grosvald et al, 2012). Thus, possibly the ideal combination of visual features that aids in learning seems to arise when the handshape parameter is marked and the sign movement is highlighted with high sonority.

Experiment 2: Sign Reproduction

The pattern of results from Experiment 1 showed that visual sonority impacts sign language acquisition. While Experiment 1 addressed perceptual learning there is still the question of whether visual sonority impacts the production of familiar and novel signs in hearing nonsigners. Here, a reproduction paradigm was used, which allowed for the tracking of reaction times for sign language production. These reaction times provide a psycholinguistic account of the role of sonority and handshape markedness on the assembly of motor programs to initiate sign production. Additionally, production accuracy can reveal the phonetic specificity of the underlying sign representation. It was hypothesized that low sonority signs and signs that contain marked handshapes will be slower to produce and contain more errors due to their increased complexity in motor programming. Additionally, since already-learned signs are going to be tested, if the phonological representation of previous

learned signs are underspecified due to their sonority or markedness (as seen in Experiment 1 results), we would expect reproduction of low sonority signs that contain a marked handshape to be more prone to error. As such, it was predicted that motoric complexity as well as underspecified representations during learning would produce slower and more erroneous sign productions.

Methods

Participants. Twenty-three of the same participants from Experiment 1 participated in this experiment immediately following Experiment 1. Two were omitted from the following analyses due to technical difficulties in video recording responses.

Materials. Thirty-two signs were included in this experiment. Sixteen of the familiar signs from Experiment 1 were included. Additionally 16 novel signs were included. The additional novel signs were delineated by high and low sonority and unmarked and marked constraints, similar to those in Experiment 1. The novel signs and familiar signs were not systemically different in any way.

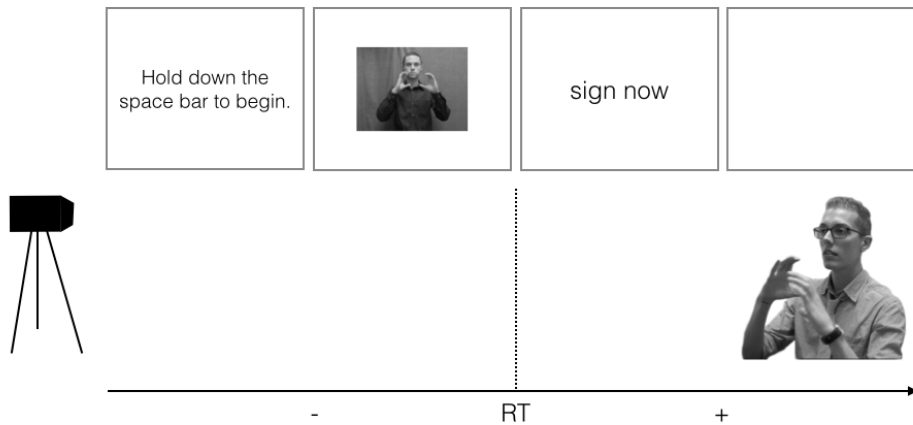


Figure 13 illustrates the design of the reproduction study. Participants were shown a sign video after holding down the space bar to begin. The participants could lift their hand and sign any time, but must be within a 3-second timeout after video offset. Reaction times were recorded relative to the video offset.

Procedure. The procedure outlined here is a paradigm that records reaction times in sign production. Older sign language production studies have captured reaction times by laser beam triggering (Corina & Hildebrandt, 2002) or motion capture (Lutpon & Zelanznik, 1990). In this study we used *PsychoPy* (Peirce, 2007) in order to capture button releases before sign production, which is similar to what more recent production studies have implemented (see Emmorey, Petrich, & Gollan, 2012; Secora & Emmorey, 2015). At the beginning of every trial the participants saw a prompt to place their dominant signing hand on the space bar. Once the space bar was held down for one second the video

would begin to play. After the video finished a prompt appeared and participants were provided a 3000 millisecond period to make their productions. The next trial did not begin until the participant pressed down the space bar (see Figure 13 for design). Although a prompt was given after the video played, participants were instructed that they could produce the sign as soon as they knew how to produce it. In order to control for participants who might lift their hands immediately and then delay their sign production, participants were additionally instructed not to lift their hands to sign without immediately producing the sign (i.e., “only lift your hands when you are completely ready to sign; do not lift your hands if you have to think about how to produce the sign”). Reaction times were calculated at the offset of the sign video. Thus, negative reaction times indicate production during the sign video and positive reaction times indicate production initiated after the video had finished (during the sign production period). In other words, negative reaction times are faster than positive reaction times. All participants were video recorded to capture sign productions for accuracy measures. Signs were given a binary accuracy score by two judges, a native signer and a proficient L2 signer (first author). A sign production was deemed accurate if the sign was produced exactly as shown by the sign model (barring any fine phonetic variation; e.g., greater finger flexion, location differences within a couple of centimeters, etc.). This means that the participants were required to produce the target signs with no handshape, movement, or location

substitutions or distortions. If judgments differed, a 100% consensus on accuracy scores was reached after discussion between the two judges.

Data analysis

A similar analysis was performed as in Experiment 1; however, an additional fixed effect of familiarity was added to the model in order to investigate how learners differ in their reproductions of familiar and novel signs.

Results

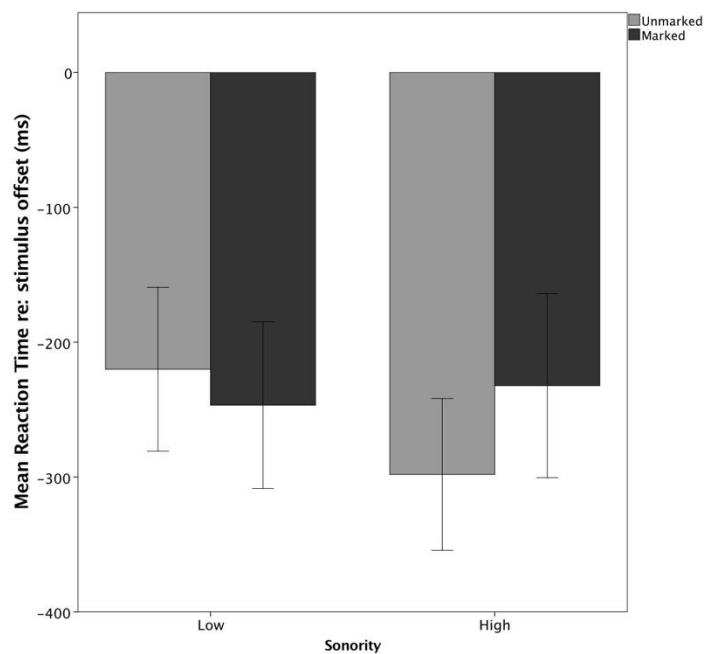


Figure 14 shows the mean reproduction times collapsed across familiar and novel signs in milliseconds relative to stimulus offset. Thus, the more negative the reaction time the faster the sign was produced (i.e., before stimulus offset), whereas the more positive the reaction time the slower

the sign was produced (i.e., post-stimulus offset). Error bars represent ± 1 SE.

Table 6. Statistics for Experiment 2 (Reproduction). Note: $F1$ = group, $F2$ = item, * = significant

Predictor	Condition		Mean	SE	$F1$ $F2$	$p1$ $p2$
	Sonority	Markedness				
Reaction Times						
Sonority*	high		-265	61	6.984 0.847	0.008 0.364
	low		-233	60		
Markedness		unmarked	-259	67	0.019 0.002	0.890 0.969
		marked	-239	65		
Sonority Markedness x	high	unmarked	-298	56	1.312 0.160	0.251 0.692
		marked	-232	68		
	low	unmarked	-220	61		
		marked	-247	62		
Accuracy						
Sonority*	high		81.3%	2.3	60.734 15.352	< 0.001 < 0.001
	low		56.5%	2.3		
Markedness*		unmarked	85.1%	1.6	104.744 26.476	< 0.001 < 0.001
		marked	52.7%	3.2		
Sonority Markedness* x	high	unmarked	93.5%	1.9	6.327 1.625	0.011 0.212
		marked	69.0%	4.3		
	low	unmarked	76.8%	3.1		
		marked	36.3%	3.0		

Reaction times were filtered for trials where the subject lifted the hands but did not produce the sign immediately and for those that fell two standard deviations above or below the mean (2.3%). Filtered reaction times from only correct trials were analyzed using the linear mixed-effect model. A significant main effect of sonority was found at the group level [$F1(1,713) = 6.984, p = 0.008; F2(1,32) = 0.847, p = 0.364$] such that high

sonority signs [-265 (61) ms] were produced more quickly than low sonority signs [-233 (60) ms]. There was no main effect of markedness [$F1(1,713) = 0.019, p = 0.890$; $F2(1,32) = 0.002, p = 0.969$] insofar as both unmarked [-259 (67) ms] and marked [-239 (65) ms] signs were produced equally as fast. However, there was a highly significant effect of familiarity [$F1(1,713) = 1407.624, p < 0.0001$; $F2(1,32) = 170.778, p < 0.0001$], where familiar signs [-688 (52) ms] were produced more quickly than novel signs [+170 (69) ms]. There was no significant interaction between sonority and markedness [$F1(1,713) = 1.312, p = 0.251$; $F2(1,32) = 0.160, p = 0.692$]. There was a significant interaction between sonority and familiarity [$F1(1,713) = 5.221, p = 0.023$; $F2(1,32) = 0.633, p = 0.432$]. There was no interaction between markedness and familiarity or a 3-way interaction [$F_s < 1$].

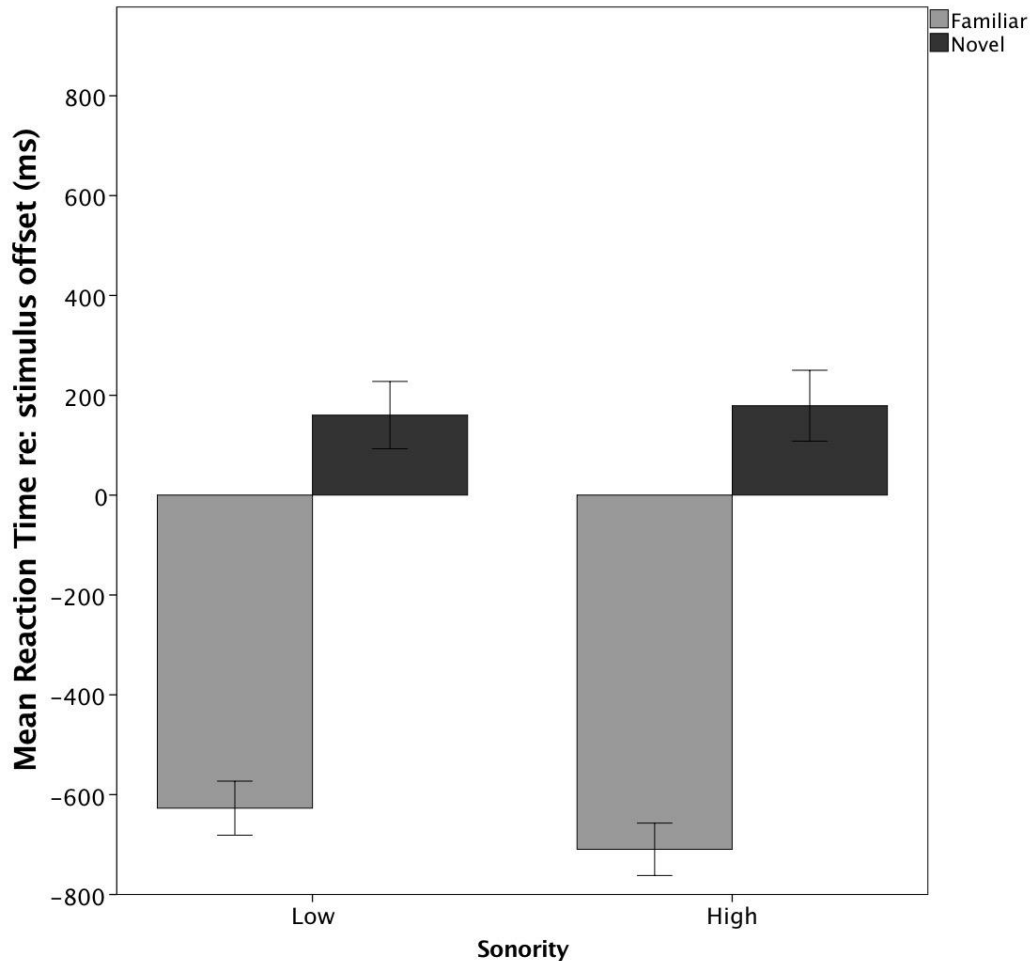


Figure 15 shows the mean reaction times (in milliseconds) for low and high sonority signs grouped by whether or not they were familiar (in Experiment 1) or novel. Reaction times are relative to the stimulus offset. Error bars represent ± 1 SE.

Planned t-tests were performed in order to tease apart the interaction effects. In regards to the familiarity effect, it is important to know if there was a high sonority advantage for only familiar signs compared to novel signs. There was a significant effect of sonority for the familiar signs [$t(22) = 4.127, p < 0.001$] such that high sonority signs [-709 (52) ms] were produced much faster than low sonority signs [-627 (54)

ms]. On the other hand, there was no sonority advantage in the reproduction of novel signs [high = 179 (71) ms, low = 160 (67) ms; $t < 1$]. There was also a difference between familiar and unfamiliar signs for both high [$t(22) = 35.825$, $p < 0.0001$] and low sonority [$t(22) = 35.242$, $p < 0.0001$], where familiar signs were produced faster than unfamiliar signs.

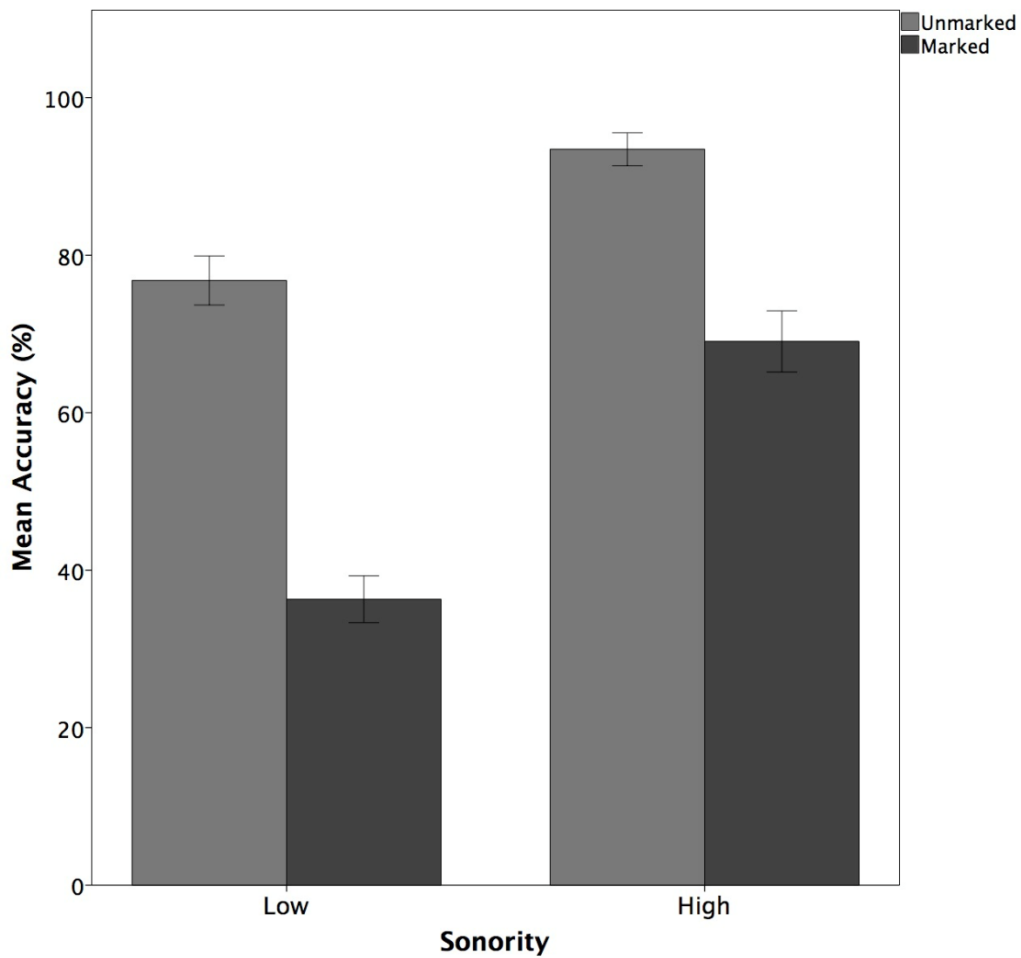


Figure 16 shows the mean accuracy in production for signs collapsed across familiarity, but separated between sonority and markedness.

Accuracy rates were also analyzed using a mixed-effects model, which revealed a main effect of sonority at both levels [$F1(1,713) = 60.734, p < 0.001$; $F2(1,32) = 15.352, p < 0.001$] such that high sonority signs [81.3% (2.3)] were produced more accurately than low sonority signs [56.5% (2.3)]. There was a main effect of markedness at both levels [$F1(1,713) = 104.744, p < 0.001$; $F2(1,32) = 26.476, p < 0.001$] such that unmarked [85.1% (1.6)] were more accurately reproduced than marked [52.7% (3.2)] signs. There was no main effect of familiarity [$F1(1,713) = 1.067, p = 0.302$; $F2(1,32) = 0.270, p = 0.607$], where familiar signs [67.3% (2.3)] were produced relatively as accurately as the novel signs [70.5% (2.6)]. There was a significant interaction between sonority and markedness at the group level [$F1(1,713) = 6.327, p = 0.011$; $F2(1,32) = 1.625, p = 0.212$] such that unmarked high sonority signs were qualitatively reproduced the most accurately [93.5% (1.9)] with unmarked low sonority signs [76.8% (3.1)], marked high sonority signs [69.0% (4.3)], and marked low sonority signs [36.3% (3.0)] being less accurate. There was a trending interaction of sonority and familiarity [$F1(1,713) = 3.183, p = 0.075$; $F2(1,32) = 0.804, p = 0.376$], due to a larger difference for the reproduction of high sonority signs compared to low sonority signs for familiar relative to novel signs. There were no other significant interactions [$F_s < 1$].

To further tease apart the interaction between sonority and markedness, planned t-tests were performed. Results indicated that all

interactions were significant. First, there was a difference between high sonority and low sonority for unmarked handshapes [$t(22) = 4.183, p < 0.001$] such that high sonority signs (93.4%) were more accurate than low sonority (76.8%) signs when they contained an unmarked handshape. The same was true when they contained a marked handshape [high: 69.1%, low: 36.3%; $t(22) = 8.830, p < 0.001$]. Second, high sonority signs that contained unmarked handshapes (93.5%) were produced more accurately than marked (69.1%) handshapes [$t(22) = 5.125, p < 0.001$]. The same held true for low sonority signs [unmarked: 76.7%, marked: 36.3%; $t(22) = 9.805, p < 0.001$]

In Experiment 2 the roles of sonority and handshape markedness on the reproduction of familiar and novel signs by hearing nonsigners were investigated. It was hypothesized that both sonority and markedness would influence the reproduction of the signs insofar as signs that contained high sonority movements and unmarked handshapes would be easier to produce due to their motoric complexity. By testing the reproduction of familiar signs and the reproduction of novel signs, we were able to test how language experience might influence the role of sonority. Results revealed an effect such that high sonority signs were reproduced faster than those with low sonority, especially when the signs were familiar. This effect was heightened when the signs contained an unmarked handshape. Markedness significantly affected production accuracy. Interactions between handshape markedness and sonority

suggest that these two interact in a coordinated way. Accuracy data revealed that motoric complexity may also impact sign language production such that marked and low sonority signs were less accurately produced than unmarked and high sonority signs, respectively. In the General Discussion, the implications of both results and how this is important to second language acquisition and sign language processing more generally are discussed.

Discussion

The goal of the current study was to investigate the role of sonority and handshape markedness on the perception and reproduction of signs. In Experiment 1 it was found that nonsigners were more accurate at matching signs that contained high sonority movements to their nonobject representations than those with low sonority movements. Additionally, the increased accuracy due to sonority was differentially modulated by handshape markedness. Another important finding is the role of sonority and markedness on sign reproduction. It was found that learners tended to produce signs with high sonority movements faster and more accurately than those with low sonority movements. As seen previously, handshape markedness affected reproduction. The results additionally showed that sonority effects were only apparent for the reproduction of familiar signs.

Sonority, or the perceptual salience of a linguistic unit, has been shown to influence spoken language acquisition and processing (Broselow

& Finer, 1991; Eckman & Iverson, 1993; Gierut, 1999; Ohala, 1999; Tropic, 1987; Yavas & Gogate, 1999). The influence of sonority has also been found to be cross-modal (Brentari et al., 2010). While there has been a great deal of research investigating the impact of sonority on spoken language, there are a number of outstanding questions regarding the relationship between sonority and sign language learning and processing. In the present study a phonetic account of sign language sonority was adopted and the characteristic of the movement parameter was varied to investigate its impact on acquisition and recall. It was hypothesized here that greater visual salience (i.e., high sonority) would facilitate acquisition by providing salient cues that would aid in sign-picture mapping in a learning paradigm. Indeed, this was the case. Learners were better at acquiring sign-nonobject mappings of novel signs that contained high sonority movements compared to those that contained lower sonority movements. Concomitant increased accuracy as a function of greater sonority suggests that learners are attuned to the most salient features in the input and exploit these features during learning.

Similarly, sonority demonstrated a facilitative role in the reproduction of familiar signs. When learners were asked to produce signs that they had just learned, learners showed faster reaction times in the reproduction of familiar signs that contained high sonority movements compared to those that contained low sonority movements. There are at least two possible explanations. First, learners may have encoded the

movement features better due to increased attention to salient cues. This would provide for greater feature specificity and learning which would facilitate subsequent sign production. A second possibility is that sonority and motoric complexity are highly correlated such that signs with high sonority movements are less motorically complex. Examining sonority alone may not be able to disambiguate the impact of motor complexity and sonority. However, handshape markedness may allow us to disentangle visual and motoric complexity.

Sonority was not the only perceptual factor that influenced sign acquisition. Handshape markedness provided additional visual and motoric complexity, which interacted with sonority during sign acquisition. The results presented show an interaction between sonority and markedness with high sonority movements and unmarked handshapes being easier to process than signs with low sonority movements and marked handshapes. From Experiment 1 when sonority is low and the handshape is marked there is greater confusion, which was largely supported by an ad-hoc confusion matrix analysis. This perceptual hierarchy is similar to Storkel's (2006) saliency ratio. Storkel found that novel words were better acquired if the novel words contained sound sequences that were not already in the child's phonological repertoire, because uncommon sounds are more salient than common sounds and they facilitate child language acquisition. Storkel's saliency ratio points to a more general process for contrastive abstraction that the human learner

uses to acquire various types of knowledge, such as language. In other words, salient features, like uncommon sounds or sonority, are only salient when they are compared to the distribution of other features. When there are varying degrees of saliency, then the learner can pick out those features that are most salient. This general process underlies statistical word learning in children (Yu & Smith, 2007) and adult L2 learning (Laufer & Girsai, 2008).

This saliency ratio can be reconceptualized in terms of movement sonority and handshape markedness by including results from this study as well as other studies (e.g., Grosvald et al., 2012). For sign learners, when the full distribution of salient features is present (i.e., high vs. low sonority; marked vs. unmarked handshapes), high sonority signs allow for movement features⁶ to pop out in the input since high sonority requires more space to be used (e.g., path movements) and larger articulatory gestures (e.g., signs articulated with the shoulder joint) relative to low sonority signs. Increased handshape markedness may additively contribute to perception when contrasted with unmarked handshapes. However, with decreased saliency, marked forms create greater confusability for learners. It may be that this saliency ratio changes with proficiency. Just as phonotactic probabilities highlight novelty and then

⁶ Movement features are likely not the only features that are salient in high sonority signs. For instance, path movements inherently require location changes. Given the location is often very salient in L2 acquisition, it could be the case that high sonority signs also allow location features to pop out. However, given the design of the present study, we are unable to directly address this theoretical point.

allow for easier learning of uncommon sounds/lexical items during language development, as a learner becomes more proficient the marked handshapes may become more salient and easier to learn. This may explain why hearing learners do better on unmarked handshapes whereas deaf signers do better with marked handshapes (i.e., marked handshapes pop out in the input for deaf signers, but are confusing at low levels of sonority for hearing sign learners).

The interaction between handshape markedness and sonority was also seen in the reproduction study. The reproduction results mirror the findings in Experiment 1, showing an interaction between sonority and handshape markedness. This suggests that visual characteristics not only influence the perception of signs, but also their reproduction. Given no difference in novel signs in their production as a function of sonority, we can say that sonority is unlikely to be treated as motoric in nature; rather, it is likely that sonority provides visual salience that allows for enhanced encoding during learning, which aids in faster recall during production. There was a notable difference insofar as sonority improved reproduction for only signs with unmarked handshape, whereas marked handshapes in high sonority signs improved learning. During perception, there is greater reliance on markedness as a perceptual constraint, while it acts more like a motoric constraint during production. Thus, it may be the case that the visual salience helps with identification and perceptual encoding, but motoric complexity is the important feature for production. Although the

acquisition study alone cannot distinguish between visual and motoric influences, it seems that the difference between the two is driven by the fact that motoric complexity is higher for marked signs (Ann, 2006; Boyes-Braem, 1990), which might decrease motor assembly and execution rates. Therefore, we can posit that the visual salience of marked handshapes is beneficial during learning, but handshape markedness is detrimental during production. These findings support some previous findings that show handshape markedness may pose challenges in adult L2 sign production (Rosen, 2004).

The combined effects of sonority and handshape in the present study, for both learning and reproduction, support a theory of additivity in visual processing. Given that learners must attend to cues in order to encode (and reproduce) signs, it may be advantageous to attend to multiple cues that maximize encoding. Just as combined auditory and visual information expedite processing (as well as many other examples of multiple cues being advantageous to cognitive processing), both sonority and handshape markedness directly (and additively) impact encoding. As such, it is important for studies to start to move away from sign language processing at the single parameter level, and begin also investigating how phonetic salience and co-occurrences of cues may impact learning and processing. This will allow our field to move toward a grander, unified theory of sign language acquisition and processing.

It is important to mention that there may be a possible confound in the present study – a correlation between sonority and number of active articulators (i.e., one-handed versus two-handed). Many of the high sonority signs were also two-handed signs. As such, it may be the case that seeing two hands as active articulators was the driving force behind improved encoding. However, this does not necessarily impact the present results insofar as increased visual salience due to two hands falls in line with our theory of sign language processing. Additionally, sign language theories have rather neglected the use of handedness in their respective sonority hierarchies. As such, further theoretical investigation is necessary to better specify these theories and de-correlate this interaction.

Additionally, there may be an alternative explanation for the present results. Given that there are various factors that were uncontrolled in the stimulus set (e.g., number of hands, body contact, etc.), learners might have followed a strategy to minimize effort by noting the most important distinguishing characteristics needed to succeed in learning, and not the salient phonetic features that were being tested. However, this is highly unlikely given that the learner would have to remember a large number of different features that are unique to each sign, which would tax the memory system and likely reduce overall accuracy and speed. Yet, overall accuracy was pretty high. The confusion matrix also provides strong evidence against this alternative explanation. If learners were able to provide one contrastive feature (e.g., location), then when two signs

shared that feature (e.g., HIGH-SCHOOL & FURNITURE) there would be a high confusion rate. As we see, this is not the case. In fact, inspection of those signs that were confused with one another revealed that often there were various differences between them. The sign pairs that were most confused did not have a common overlapping feature; instead each pair had a different feature in common. For example, PUZZLED and ASK share handshape (i.e., F), HIGH-SCHOOL and JOIN share major location (i.e., neutral space), and COMMUNICATION and PUZZLED share no common feature. Furthermore, there is no confusion between two signs that share location (COMMUNICATION and VOMIT) or handshape (AUDIOLOGY and SORRY). As such, the confusion matrix seems to rule out any common phonetic feature that learners were attuning to which could explain our results. Nevertheless, more experimental investigations are needed in order to advance our knowledge on the impact of salient features in sign acquisition.

The results of the present study may also inform the overarching theories of sign language phonology. Given the phonetic account of sonority (based on articulating joint and movement characteristics; Brentari, 1990; Sandler, 1993) it may be the case that naïve learners attune to movement features more specifically. In other words, naïve learners may be attuned to the phonetic correlates of sonority. Although we cannot rule out the possibility that learners are also sensitive to typological or allowable patterns, it seems to be the case that learners can

still use phonetic (and not necessarily phonological) cues when learning, especially given that they are unaware of the frequency distributions or phonotactics of sign language (cf. Corina, 1993). Again, more research is needed to further explore the cues used during the initial stages of acquisition.

Not only do the results from the present study inform theories of sign phonology, but also theories on lexical access in sign language. Gating studies have demonstrated that access to phonetic-phonological information occurs early within the sign, with lexical access occurring before the entire sign is completed — often within the first 300 milliseconds (Emmorey & Corina, 1990; Morford & Carlson, 2011). In the present study, familiar signs were produced before the end of the target stimulus, while novel signs were produced after the target was finished. This finding supports theories that sufficient phonological information is stored within the first portion of the sign, which triggers recognition, but the learner must wait until the entire sign is produced before reproduction when there is no lexical representation to recall. Although this was a tangential finding, we argue that this finding extends previous research on lexical access in recognition to production.

Beyond theoretical insights, the present study may also have a practical impact. The results from the present study lend themselves to future research on second language acquisition and pedagogy. Previous studies have shown that movement is harder to acquire than other

sublexical features (Bochner et al., 2012). However, this study has shown that signs are accurately acquired (~91%) if they contain high sonority movements. Thus, if high sonority signs can be taught first, learners may be able to encode movement characteristics much more easily. The encoding of movement features may help with the acquisition of certain signs. Moreover, this may have positive effects downstream in terms of production development. Along the same vein, late L2 learners master handshape features much later (Bochner et al., 2012; Morford & Carlson, 2011). Therefore, if marked handshapes are paired with high sonority movements, learners may acquire the phonetic characteristics earlier. The findings presented herein provide new ways to conceptualize the teaching of lexical items based on phonological characteristics. Furthermore, this study demonstrates the need to control for sonority and handshape markedness in future sign language perception research.

Chapter 6: Discussion: Modality Adaptation Hypothesis

The aim of this dissertation was to provide some emerging neurobiological and psycholinguistic evidence that advances a new hypothesis that hearing adults lack efficient modality-specific neurocognitive processing routines to support sign language processing and acquisition. This dissertation drew upon already published data from various areas to provide support for this hypothesis, including four published works from our lab. In this section, support for the Modality Adaptation Hypothesis (MAH) will be recapitulated and implications will be explained.

Modality Adaptation Hypothesis

The MAH posits that hearing adults are hindered from rapidly and efficiently acquiring sign language due to having spent a lifetime refining and automatizing modality-specific aural-oral mechanisms in order to process language with only auxiliary support from the visual-manual modality. Hearing individuals' neurocognitive system is highly attuned to sequentially ordered acoustic information (Burton, Small, & Blumstein, 2000; Zatorre, Evens, Meyer, & Gjedde, 1992; Zatorre, Meyere, Gjedde, & Evens, 1996), which is molded by experience with their first (spoken) language. Sign languages are distinctly different from their input-output signal when compared with speech. Particularly, sign languages are dependent on robust and dynamic visuospatial dependencies at all levels of linguistic analysis, from phonetics to discourse pragmatics, as primary

linguistic units (Emmorey, 2001; Sandler & Lillo-Martin, 2006)⁷. Consequently, sign language acquisition and processing depends on both sequentially and simultaneously ordered linguistic information. This divergence between language modalities and the unbalanced allocation of neurocognitive resources produces a significant roadblock in sign language acquisition. Namely, second language learners have difficulty with acquiring the movement parameter, which is consequently important for phonological and, especially, morpho-syntactic processing.

The first set of experiments from Chapters 2 and 3 provided evidence of sign language induced neuroplasticity and neural biomarkers of M2L2 success. Hearing adults showed relatively little differentiation in the activation patterns between viewing ASL sign and a simple fixation baseline when first exposed to sign language, despite performing a phonological categorization task. However, with subsequent exposure to sign language, the learners showed increased activation to bilateral parietal and temporal-occipital cortex. Prior studies have implicated these regions in sign language phonological processing, visuospatial processing, and biological motion processing (e.g., see Emmorey, 2001

⁷ The use of “primary” is important here. This discussion will largely ignore the fact that speech is multimodal and often accompanied by co-speech gesture. It is argued that these multimodal cues, including co-speech gesture, are complementary, or to a certain extent redundant, to the acoustic signal and are ultimately not *necessary* for spoken language processing, even if they do ultimately aid in perception and production in various scenarios. However, I will touch on co-speech gesture transfer in M2L2 acquisition, which will support this idea for modality-specific plasticity.

for review). As such, it is posited that these learners were showing extensive neuroplasticity in their modality-specific visual-manual processing of sign language. Furthermore, a subsequent study revealed that those learners who had poor lexicosemantic acquisition required greater neural recruitment in these same regions (i.e., temporoparietal junction, middle temporal gyrus), suggesting less efficient neural mechanisms in movement-related processing when viewing sign language.

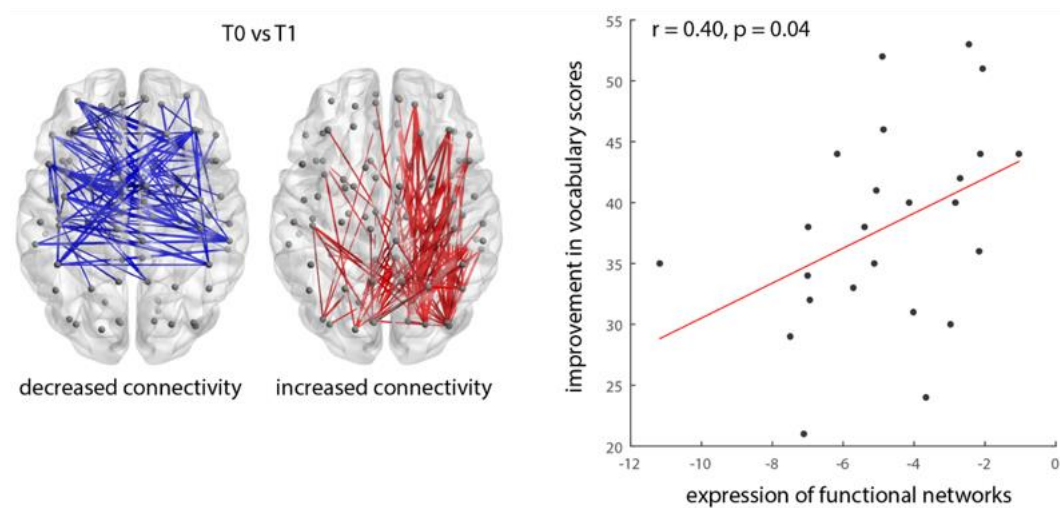


Figure 17 shows a preliminary Partial Least Squares analysis on the longitudinal data from Chapters 2 and 3. The analysis examined whether the functional connectivity changed as a function of greater sign language experience and whether expression of given connectivity patterns could predict sign language proficiency. The results showed that there was neuroplasticity in the functional connectivity in the right temporoparietal cortex. Additionally, this increased connectivity pattern was able to predict

vocabulary acquisition insofar as those learners who had better functional connectivity in right temporoparietal cortex also had proportionally larger growth in vocabulary knowledge ($r = 0.4$, $p = 0.04$).

Other researchers have found similar results when examining the neural correlates of sign language proficiency in the brain. It has been suggested that the right temporoparietal cortex may act as a biomarker for sign language proficiency. A. Newman and colleagues (2001) suggested that only high proficiency signers, monolingual or bilingual, recruit the right angular gyrus for sign language processing. In fact, pilot data from our lab (see Figure 17) shows that there is a large amount of neuroplasticity in the functional connectivity between the right temporoparietal cortex and the rest of the brain. More importantly, the extent to which a learner underwent similar neuroplasticity predicted their long-term vocabulary outcomes. This preliminary finding suggests that right hemispheric processing, especially in terms of visuospatial and motion processing, likely contributes significantly to the proficiency of a signer. Cardin and colleagues (2015) showed similar results to the study in Chapter 3 in that inexperienced signers required bilateral temporoparietal activation compared to native signers when making phonological judgments. In other words, low proficiency learners show less functional connectivity in the right temporoparietal cortex and recruit greater neural resources in this area when viewing sign language compared to higher proficiency or native

signers. This pattern of results suggests that the right temporoparietal cortex may be a potential biomarker for sign language proficiency; more importantly, however, it also suggests that visuospatial and motion processing deficits are biomarkers of sign language proficiency, which lends support to the MAH.

Not only have neurobiological findings supported the idea of visuospatial and motion processing deficits in learners, but also behavioral studies have shown a consistent and robust deficit in movement-related processing. Bochner and colleagues (2011) was one of the first studies to nicely delineate movement processing deficits in M2L2 learners using psycholinguistic (and standardized) measures. Bochner et al. found that M2L2 learners showed dramatic difficulty discriminating between signs that differed in their movement specification compared to other contrasts (e.g., handshape, location, and orientation). Additionally, Bochner et al. found that morphosyntactic processing was also a deficit in these learners. If you recall, morphosyntactic alternations in sign languages is almost exclusively encoded by movement information (Sandler & Lillo-Martin, 2006). Bochner's findings supported previous accounts of movement deficits in both perception and production (e.g., Mirus, 2010; Rosen, 2012). Additionally, the findings from Chapter 4 showed perceptual problems with movement processing in an ASL-to-English translation task. M2L2 learners had even more difficulty in movement processing when another M2L2 learner produced the stimuli compared to a native signer,

which suggests that the M2L2 model likely produced altered movement which directly impacted the interlocutors' poor movement perception. Together, psycholinguistic and neurobiological data suggest that visuospatial and motion processing, which are key modality-specific features of sign language, are difficult to acquire and learners require drastic neuroplastic reorganization in order to accommodate for these modality-specific features.

It may be the case that if a learner has experience with visuospatial or motion processing that they may be better sign language learners. Two previous studies have shown that learners capitalize on co-speech gesture in order to acquire sign language (Brentari et al., 2012; Chen Pichler, 2011). It might be the case that learners who are used to attending to and producing gesture are better learners because their neurocognitive mechanisms are robustly efficient and automatized. This will be discussed more in the future work section (6.2), but this observation does provide potential food for thought in terms of positive evidence for the MAH. Furthermore, despite learners' difficulty with movement, learners can in fact leverage movement features in order to *aid* in language acquisition. Data from Chapter 5 showed that M2L2 learners can rapidly acquire signs when movement features are salient (i.e., sonority is maximal) and the only contrastive information in the signal. Therefore, by highlighting the movement features, learners can better encode their phonological specification for subsequent production. It

may be the case that learners pick an incorrect learning strategy when acquiring sign language in that they focus on hand configuration and palm orientation. In fact, many previous studies have found an overreliance on attention to handshape when first learning sign language (Emmorey et al., 2009; Geer, 2016; Grosvald et al. 2012; Morford & Carlson, 2011). Therefore, these processing deficits may be in part due to the extant neurobiological structure and function of the learner, but also could be due to incorrect learning strategies and a propensity for attending to hands and not gross brachiomaneal movement. Nevertheless, these data support the MAH insofar as prior extensive experience with an auditory-oral language biases these learners to either not attend to all of the pertinent phonological information and/or have poor neurocognitive mechanisms for dealing with robust dynamic visuospatial properties.

In conclusion, the vast differences in language modalities and their optimal processing strategies (i.e., simultaneous vs. sequential) lead to deficits in visuospatial and motion processing in late hearing adult learners of sign language. The Modality Adaptation Hypothesis (MAH) was developed in order to characterize these patterns and is supported by emerging neurobiological and psycholinguistic data, which was presented herein. Evidence suggests that perhaps there are potential neural biomarkers for sign language proficiency, but also behavioral evidence that these deficits could be remediated with appropriate intervention. The MAH has important implications to our theories of neuroplasticity,

language learning, modality differences, and second language pedagogy. Future work is needed in order to validate the MAH and to create possible interventions to reduce such deficits.

Implications and Future Work

As previously mentioned, the Modality Adaptation Hypothesis (MAH) has both theoretical and practical implications. On a theoretical note, the MAH supports the idea that learning second languages alters the neurocognitive system in meaningful and dramatic ways (e.g., Li et al., 2014). Never reported before, I can posit that learning a language in a new modality might drastically alter the neurocognitive system to a greater extent than within-modality acquisition – similar to what is seen with cross-modal plasticity in blind or deaf individuals (e.g., Bavelier & Neville, 2002; Cohen et al., 1997). On a practical note, it is important to discover ways, both in terms of pedagogy but also neuro-hacking, to reduce modality-specific roadblocks and expedite neuroplasticity.

Future work is needed to replicate, validate, and refine the MAH in order to provide a clear theoretical framework for sign language acquisition and neuroplasticity. Additionally, it might be important to understand whether these deficits really generalize to all motion processing (e.g., actions) or whether semantic movements that are linguistically relevant are only affected. In order to contribute to the MAH possible predictors for sign language outcomes might be needed. For

example, is it the case that more frequent gesturers are better sign language learners due to positive transfer from their L1 co-speech gesture system to their L2 sign system? Lastly, it is crucial that we find potential interventions to aid in the reducing the nefarious effects that are implied by the MAH. For example, perhaps neuro-hacking (e.g., transcranial magnetic stimulation or transcranial direct current stimulation) could be included in sign language programs. Other possibilities could include developing explicit training in movement identification using course materials that are organized by their movement saliency. Any of these interventions would not only improve sign language outcomes and fluency, but would also contribute to theoretical endeavors. It is important to not forget the practical implications, because at the end of the day, many of these sign language learners will become professionals in Deaf-centered communities (e.g., interpreters, teachers for the Deaf), which directly impact those Deaf individuals. In sum, the MAH makes testable predictions that can be validated in future empirical studies that have robust impacts on theory and society.

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Appendix

Appendix Table 1: fMRI Stimuli (Chapters 2 & 3)

Head	Not Head
HOME	TIME
DRINK	NIGHT
FOOD	WORK
PARENTS	HAPPY
BORED	TOILET
MISS	WEEK
SEARCH	SORRY
CANDY	MILK
DEAF	PLAY
SICK	SAME
MAN	FEEL
WOMAN	LIFE
GIRL	GAME
BOY	SCHOOL
LAUGH	HARD

Appendix Figure 1: Chapter 5

A1. Depictions of the handshapes used in this study

Unmarked		Marked	
B		F	
A		H	
C		X	
1		8	

[Note: 5 and B are often lumped within the same handshape family.] Images downloaded from the Centre for Sign Language Linguistics & Deaf Studies website with permission (www.cslds.org).

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EDUCATION

Indiana University Sciences	Ph.D. 2017	Psychological & Brain Cognitive Science
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Dissertation: *“Modality Adaptation Hypothesis: Neurocognitive Alterations to Novel Visuospatial Components of Sign Language”*

Indiana University Sciences	M.A. 2016	Speech & Hearing
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University of Kansas Sciences (Honors)	B.A. 2012	Linguistics (Honors) Speech & Hearing Research Certification Service Learning
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Certification

EXPERIENCE

Adjunct Lecturer (2014 – 2017)	Speech & Hearing Sciences Indiana University
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NSF Graduate Research Fellow (2014-2017)	Indiana University
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Graduate Research Assistant (2012 – 2017)	Cognitive Neuroimaging Lab Indiana University Dr. Sharlene Newman
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Affiliated Research Assistant Psycholinguistics Lab (2012 – 2017)	Second Language Indiana University Dr. Isabelle Darcy
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Visiting Research Assistant (2013 – 2014)	Lab for Language and Cognitive Neuroscience San Diego State University Dr. Karen Emmorey
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NSF Graduate IGERT Trainee	Indiana University
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(2012-2014)

Undergraduate Research Assistant
Psycholinguistics Lab
(2010 – 2012)

Phonetics and
University of Kansas
Drs. Allard Jongman and Joan

Sereno

JOURNAL PUBLICATIONS (see: [ASLEXICON](#) or [ResearchGate](#))

Neural Representations of Language

1. **Williams, J.T.**, Darcy, I., Newman, S.D. (2016). Modality-specific processing precedes amodal linguistic processing during L2 sign language acquisition: a longitudinal study. *Cortex*, 75, 56-67. doi: 10.1016/j.cortex.2015.11.015
2. **Williams, J.T.**, Darcy, I., & Newman, S.D. (2015). Modality-independent neural mechanisms for novel phonetic processing. *Brain Research*, 1620, 107-115. doi: 10.1016/j.brainres.2015.05.014

Phonetic and Phonological Perception and Production of Sign Language

3. **Williams, J.T.**, & Newman, S.D. (in press). Phonological substitution errors in L1 ASL sentence processing by hearing M2L2 learners. *Second Language Research*, 32(3), 347-366. doi: 10.1177/0267658315626211
4. **Williams, J.T.**, & Newman, S.D. (2016). Impacts of visual sonority and handshape markedness on second language learning of American Sign Language. *Journal of Deaf Studies and Deaf Education*, 21(2), 171-186. doi: 10.1093/deafed/env055
5. **Williams, J.T.**, & Newman, S.D. (2016). Interlanguage dynamics and lexical networks in nonnative L2 signers of ASL: Cross-modal rhyme priming. *Bilingualism: Language and Cognition*, 19(3), 453-470. doi: 10.1017/S136672891500019X
6. **Williams, J.T.**, & Newman, S.D. (2015). Modality-independent effects of phonological neighborhood structure on initial L2 sign language learning. *Research in Language*, 13(2), 199-213. doi: 10.1515/rela-2015-0022

M2L2 Acquisition and Neurobehavioral Predictors

7. **Williams, J.T.**, Darcy, I., Newman, S.D. (in press). The beneficial role of L1 spoken language skills on initial L2 sign language learning: Cognitive and linguistic predictors of M2L2 acquisition. *Studies in Second Language Acquisition*.

8. **Williams, J.T.**, & Newman, S.D. (in press). Spoken language activation alters subsequent sign language activation in L2 learners of American Sign Language. *Journal of Psycholinguistic Research*. doi: 10.1007/s10936-016-9432-4
9. **Williams, J.T.**, Darcy, I., Newman, S.D. (2016). Bimodal bilingualism as multisensory training?: Evidence for improved audiovisual speech perception after sign language exposure. *Brain Research*, 1633, 101-110.
10. **Williams, J.T.**, & Darcy, I., & Newman, S.D. (2015). Second language working memory deficits and plasticity in hearing bimodal learners of sign language. *Psychology of Language & Communication*, 19(2), 128-148. doi: 10.1515/plc-2015-0008.

Manual Codes and Reading

11. **Williams, J.T.**, & Newman, S.D. (2016). Connections between fingerspelling and print: The impact of working memory and temporal dynamics on lexical activation. *Sign Language Studies*, 16(2), 157-294.
12. **Williams, J.T.**, Darcy, I., & Newman, S.D. (2015). Fingerspelling and print processing similarities in deaf and hearing readers. *Journal of Language and Literature*, 6(1), 56-65. doi: 10.7813/jll.2015/6-1/12.

Other

13. **Williams, J.T.**, & Johnson, T.J. (2011) Sex differences and otoacoustic emissions: Examining underlying cochlear mechanisms. In Fracol and Thomas (eds.), *The University of Kansas Journal of Undergraduate Research* (3rd ed): Lawrence, KS, 7-10.

MANUSCRIPTS UNDER REVIEW OR IN PREPARATION (*results available upon request*)

1. **Williams, J.T.**, Darcy, I., Newman, S.D. (in review). Poor M2L2 sign language vocabulary knowledge engages modality-independent lexico-semantic and modality-dependent hand and movement neural processing.
2. **Williams, J.T.**, Robinson, C., & Newman, S.D. (in review). Speech perception in bimodal and unimodal L2 learners: bimodal bilingual advantage.
3. **Williams, J.T.**, Stone, A., & Newman, S.D. (in review). Operationalization of Phonological Similarity and Neighborhood Density in American Sign Language: Impacts on Lexical Access

4. **Williams, J.T.**, & Newman, S.D. (in prep). Effects of L1 spoken language phonological neighborhood structure and iconicity on M2L2 lexical access.
5. **Williams, J.T.**, Stone, A., Bosworth, R., & Newman, S.D. (in prep). Neural correlates of visual sonority: Evidence for experience-based neuroplasticity and perceptual tuning.
6. **Williams, J.T.**, & Newman, S.D. (in prep). M2L2 Sign Language Acquisition Causes Multimodal Cue Interference.

GRANTS AND HONORS

Grant	Institution	Description	Date
NIMH ERP Boot Camp	UC-Davis, Brain and Mind Institute	Methodological Training Scholarship	July 2016
NSF VL2 Student Research Grant	VL2, Gallaudet University	Research Grant (PI; \$3000)	2016 - 2017
NSF IGERT Development Grant	Indiana University	Travel Grant (\$6,475)	July 2015
NSF IGERT Development Grant	Indiana University	Travel Grant (\$1,940)	May 2015
NSF Graduate Research Fellowship	National Science Foundation, Indiana University	Fellowship (\$130,000)	2014 - 2017
Brain Scan Credit Grant	Indiana University Imaging Research Facility	Research Grant (PI, \$48,000)	2014 - 2015
NSF VL2 Review Grant	VL2, Gallaudet University	Travel Funding (\$700)	2014, 2015, 2016
NSF IGERT Development Grant	Indiana University	Travel Grant (\$1,720)	October 2014
NSF IGERT Development Grant	Indiana University	Travel Grant (\$2,025)	July 2013

NSF IGERT Development Grant	Indiana University	Educational Grant (\$2,250)	May – August 2013
NSF IGERT Traineeship	National Science Foundation, Indiana University	Fellowship (\$113,000)	2012 - 2014
Undergraduate Research Award	University of Kansas	Research Grant (\$2,625)	2011 - 2012
Undergraduate Research Award	University of Kansas	Research Grant (\$2,000)	2010 - 2011

<i>Honor/Award</i>	<i>Institution</i>	<i>Description</i>	<i>Date</i>
Cognitive Science Graduate Research Award	Indiana University	Annual award for exceptional graduate research	2016
Dean's Scholar	University of Kansas	Professional development courses and monies for the Top 5 University Honors Students	2011 - 2012
Sigma Xi Undergraduate Research Award (1 st Place)	University of Kansas	Annual award for best undergraduate research presentation	2012
Margaret C. Byrne Saricks Research Award	University of Kansas	Annual award for best undergraduate research in the Speech and Hearing Department	2012
Undergraduate Student Service Award	University of Kansas	Annual award for outstanding service to the community and to the department	2011
Margaret C. Byrne Saricks Research Award	University of Kansas	Annual award for best undergraduate research in the Speech and Hearing Department	2011
Ex.C.E.L Award	University of Kansas	Annual award to the top 5 upperclassmen for excellence in community, education, and leadership	2011

TALKS AND POSTER PRESENTATIONS

1. **Williams, J.T.**, Stone, A., Bosworth, R., & Newman, S.D. (January, 2017). Neural correlates of sonority: An investigation of fingerspelling. Invited Symposium Presentation at 2017 Linguistic Society of American Annual Meeting, Austin, TX.
2. **Williams, J.T.**, & Newman, S.D. (October, 2016). L2 American Sign Language lexical access: Effects of spoken phonological neighborhood density and iconicity. Paper accepted at *Mental Lexicon 2016*, Ottawa, Canada.
3. **Williams, J.T.**, Robinson, C., & Newman, S.D. (October, 2016). Enhanced audiovisual speech perception after sign language exposure: M2L2 ASL learners outperform M1L2 Spanish learners on an L1 English speech perception task. Paper presented at *Bilingual Forum*, Chicago, IL.
4. Robinson, C., **Williams, J.T.**, & Newman, S.D. (May, 2016). Enhanced Audiovisual Speech Perception in Adult Hearing Learners of American Sign Language. Paper presented at the *Midwest Undergraduate Cognitive Science Conference*, Bloomington, Indiana.
5. **Williams, J.T.**, Stone, A., & Newman, S.D. (January, 2016). Modality-Independent Mechanisms for Language Production: Phonological Neighborhood Structure Impacts Sign Language Production. Paper accepted at the *Theoretical Issues in Sign Language Research (TISLR) 12*, Melbourne, Australia.
6. **Williams, J.T.**, & Newman, S.D. (January, 2016). Spoken Phonological Neighborhood Structure Influences Sign Activation in Bimodal Bilinguals. Paper accepted at the *Theoretical Issues in Sign Language Research (TISLR) 12*, Melbourne, Australia.
7. **Williams, J.T.**, & Newman, S.D. (January, 2016). Grey Matter Plasticity During Initial Stages of Adult L2 Sign Language Acquisition. Poster accepted at the *Theoretical Issues in Sign Language Research (TISLR) 12*, Melbourne, Australia.
8. **Williams, J.T.** (September, 2015). Enhanced spatial working memory and sign language exposure: A longitudinal neuroimaging study of M2L2 learners. Paper presented at the *Visual Language and Visual Learning Center Lecture Series*, Gallaudet University, Washington, D.C.
9. **Williams, J.T.**, & Newman, S.D. (September, 2015). Sign phonetic correlates of movement sonority and handshape markedness modulate L2 ASL acquisition. Paper session presented at *20th meeting of the Mid-Continental Phonetics & Phonology Conference*, Bloomington, IN.

10. **Williams, J.T.,** & Newman, S.D. (September, 2015). Phonological substitution errors in L2 ASL sentence comprehension: Negative impact of movement variability. Poster session presented at *20th meeting of the Mid-Continental Phonetics & Phonology Conference*, Bloomington, IN.
11. **Williams, J.T.,** & Newman, S.D. (July, 2015). Lexical Networks in Nonnative L2 Signers of ASL. Paper session presented at *International Conference on Sign Language Acquisition*, Amsterdam, The Netherlands.
12. **Williams, J.T.,** Darcy, I., & Newman, S.D. (May, 2015). Working Memory in Second Language Acquisition Effects of Interlanguage Dynamics and Modality. Paper session presented at *Tenth International Symposium on Bilingualism*, New Brunswick, NJ.
13. **Williams, J.T.,** & Newman, S.D. (April, 2015). Modality-Independent Neural Mechanisms for Novel Phoneme Discrimination in ASL and Spanish. Poster presented at *2015 NSF IGERT Symposium*, Indiana University. Bloomington, IN.
14. **Williams, J.T.,** Bent, T., & Newman, S.D. (October, 2014). Interlanguage Speech Intelligibility Benefit: What about Bimodal Bilinguals? Paper presented at *Visual Language and Visual Learning Center Lecture Series*, Washington, D.C.
15. **Williams, J.T.,** Bent, T., & Newman, S.D. (October, 2014). Interlanguage Speech Intelligibility Benefit: what about sign language?. Paper presented at *Second Language Research Forum*, Columbia, SC.
16. **Williams, J.T.,** Darcy, I, & Newman, S.D. Native Deaf and Hearing Second Language (M2L2) Signers' Lexical Structure: Fingerspelling. (July, 2013). Poster presented at *Theoretical Issues in Sign Language Research 11*, London, England.
17. **Williams, J.T.,** Darcy, I, & Newman, S.D. (April, 2013). Orthographic and Fingerspelling Lexical Interaction in Native Signers and L2 Learners. Poster presented at *NSF IGERT Symposium*, Indiana University, Bloomington, IN.
18. **Williams, J.T.,** (September, 2012). Fingerspelling and Priming: Semantics and Form. Paper presented at *Indiana University Second Language Studies Colloquium*, Indiana University, Bloomington, Indiana.
19. **Williams, J.T.,** (April, 2012). Lexical Access in Native and Non-Native Signers of ASL: A Fingerspelling Priming Paradigm. Paper

presented at *University of Kansas Undergraduate Research Symposium*, Lawrence, KS.

20. **Williams, J.T.**, & Johnson, T. (March, 2012). Sex Differences and Otoacoustic Emissions: Examining Underlying Cochlear Mechanisms. Poster presented at *American Auditory Society*, Scottsdale, AZ.
21. **Williams, J.T.** (December, 2011). MEG/EEG Study of Lexical Integration in Individuals with Broca's Aphasia. *University of Kansas Speech-Language-Hearing Honors Research Symposium*, Lawrence, KS.
22. **Williams, J.T.** (April, 2011). Sex Differences and Otoacoustic Emissions: Examining Underlying Cochlear Mechanisms. *University of Kansas Undergraduate Research Symposium*, Lawrence, KS.

INVITED LECTURES

23. **Williams, J.T.** (Fall, 2013). "ASL Linguistics: Comparative Lecture to Spoken Language Linguistics", *Introduction to the Study of Language*, Indiana University
24. **Williams, J.T.** (Fall, 2013). "Neuro-Cognitive and Linguistic Implications of Deafness", *Neuropsychology of Language*, Indiana University
25. **Williams, J.T.** (Spring, 2012). "Morphosyntax in Kaqchikel", *Structures in Kaqchikel Maya*, University of Kansas.

TEACHING & MENTOR EXPERIENCE

Structure of ASL (2016-2017), Indiana University

Instructor of Record and Course Creator. This course was open to all students in Linguistics, Second Language Studies, and Speech and Hearing Sciences. The course provided an overview of linguistic features of American Sign Language, including phonetic, phonology, semantics, morphology, syntax, neurolinguistics, and language acquisition.

Multiple Perspectives on Deafness (2014-2016), Indiana University

Instructor of Record and Course Creator. Avg. Course Rating = **4.6/5**. The course was open to upperclassmen Speech and Hearing students. The course explored the sociocultural

aspects of deafness and evidence-based practice in relation to bilingualism, biculturalism, cochlear implants, and aural rehabilitation. Almost 100% of the student reported having a more positive perspective on Deafness/Deaf culture after taking the course; 50% of students changed their career path to be more inclusive of deaf people and/or to a Deaf-centered field.

Honors Freshman Seminar (2012), University of Kansas

Teaching Assistant. Avg. Course Rating = 5/5. The course was open to freshman in the Honors Program. The course explored the history and development of language and music as a theme. The course also provided introduction to the University and Student Life.

MENTOR EXPERIENCE

Undergraduate Honors Thesis Director

Catelin Robinson, Speech & Hearing with PBS minor (honors thesis advisee)

Caity Rogers, Speech & Hearing (audiology; honors thesis advisee)

Ungraduated Research Assistant Coordinator

Courtney Watson, Psychology & Brain Sciences and Speech & Hearing Sciences

Kellie Bubala, Psychological & Brain Sciences and History

Lacey Caplinger, Linguistics

Edwin Rivera, Psychological & Brain Sciences

Artiender Nehra, Neuroscience

Jaime Abramson, Psychological & Brain Sciences

Kaylee Mickens, Social Welfare

Jeremy Keaten, Speech & Hearing Sciences and Linguistics

Savannah Meslin, French and Linguistics

Shelby Farmer, Speech & Hearing Sciences

Tyler Carie, Psychological and Brain Sciences

Tyler Kwiatkowski, Speech & Hearing

Kate Witham, Speech & Hearing (audiology)

Hayley Flyer, Speech & Hearing

Kourtney Stevens, Speech & Hearing (audiology)

Hub for Online Psycholinguistic Experiments (HOPE) Development

Team

Joshua Williams, Project Leader
Deepa Kasi Nathan, Back-end Developer
Wen Li, Front-end Developer
Roger Rhodes (IU PBS Dept.), IT Support

SERVICE

PROFESSIONAL ASSOCIATIONS

Sign Language Linguistics Society
Linguistics Society of America
Association of Psychological Science
Psychonomic Society
Visual Language and Visual Learning (VL2) Student Network
Phi Beta Kappa
Sigma Xi Scientific Research Society
Delta Epsilon Iota Academic Honor Society

REVIEWER

Nature; PLoS One; The Open Psychology Journal; Journal of Psycholinguistic Research

SERVICE/ACADEMIC SUPPORT POSITIONS

2016 – 2017 VL2 EELS Cross-Institutional Research Team Leader, Early Education Longitudinal Study Grant, PI: Thomas Allen. Gallaudet University, Washington, D.C.
2015 – 2017 VL2 Lecture Coordinator, SFA5 Leader, and MOU Representative, VL2 Student Leadership Team, National Science Foundation (NSF) Center for Learning: Visual Language and Visual Learning (VL2), Gallaudet University, Washington, D.C.
2014 – 2015 Planning Committee Officer, *Preparing Future Faculty Conference*, Indiana University, Bloomington, Indiana
2014 – 2015 Graduate Focus Group on the Indiana University Bloomington Campus Strategic Plan by Provost and Executive Vice President Lauren Robel, moderated by Dean David Daleke
2013 – 2015 Awards Committee Officer, Graduate and Professional Student Organization, Indiana University
2013 – 2014 Bloomington Faculty Council's Educational Policies Committee Officer, Graduate and Professional Student Organization, Indiana University

- 2012 Panelist for “What is it like to be a graduate student?” in Psychology 101, Fall 2012, Indiana University
- 2011 – 2012 Senior Peer Advisor, Academic Advising Center, University of Kansas
- 2011 – 2012 Hawk Week Assistant, Office of First Year Experience, University of Kansas
- 2011 – 2012 Departmental Undergraduate Liaison, Speech-Language-Hearing, University of Kansas
- 2010 – 2012 Peer Advisor, Academic Advising Center, University of Kansas
- 2010 – 2012 Student Ambassador, Office of Undergraduate Admissions, University of Kansas

CLINICAL EXPERIENCE

- 2014 – 2017 Level 2 Magnetic Resonance Imaging (MRI) Operator, Indiana University Imaging Research Facility, Indiana University, Bloomington, IN
- 2015 Clinical Observations and Volunteer, Voice Clinic of Indiana, Carmel, IN (16+ hours)
- 2011 – 2012 Para-Student Speech-Language Pathologist, Scheifelbusch Speech-Language-Hearing Clinic, University of Kansas (20+ hours)
- 2011 – 2015 American Speech Language Hearing Association (ASHA) Certified Clinical Observation Hours, Scheifelbusch Speech-Language-Hearing Clinic, University of Kansas (25 hours)
- 2010 – 2011 Hospital Volunteer, Lawrence Memorial Hospital, Lawrence, Kansas. (100+ hours)
- 2008 Student Clinic Intern and Interpreting Aid, Cabot Westside Medical and Dental, Kansas City, Missouri. (300+ hours)
- 2007 Summer Scholar Program, University of Missouri-Kansas City School of Medicine, Kansas City, Missouri. (80+ hours)

REFERENCES

Sharlene D. Newman, Ph.D.
Associate Vice Provost for
Undergraduate Education
Associate Professor
Psychological and Brain Sciences
Indiana University
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