12-1-2012

Coarticulation in American Sign Language Fingerspelling

Caitlin S. Channer

Caitlin S. Channer
Candidate

Linguistics
Department

This thesis is approved, and it is acceptable in quality and form for publication:

Approved by the Thesis Committee:

Jill P. Morford, Chairperson

Sherman Wilcox

Phyllis Perrin Wilcox

Coarticulation in American Sign Language Fingerspelling

by

Caitlin S. Channer

BA English Language, Brigham Young University, 2010

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of

Masters of Arts
Linguistics

The University of New Mexico
Albuquerque, New Mexico

December 2012

ACKNOWLEDGEMENTS

I would like to thank my advisor and committee chair, Jill Morford, for the guidance she provided me throughout my studies and the process of this project. I am also grateful to Sherman Wilcox, for the idea and the video that started me down this road, and to Phyllis Wilcox for her gracious feedback and encouragement. I will always appreciate the selfless gift of their time and assistance.

I am also grateful for my peers who were willing to be a part of my study. Thank you for allowing me to use your skills in my research.

To my parents, family, and friends, thank you for your support and encouragement throughout the years.

To Mike, thank you for standing by me. I dedicate this, and everything else, to you.

Coarticulation in American Sign Language Fingerspelling

by

Caitlin S. Channer
B.A., English Language, Brigham Young University, 2010
M.A., Linguistics, University of New Mexico, 2012

ABSTRACT

Fingerspelling is a category of American Sign Language (ASL) signs that are signed sequentially as an alphabetic representation. The present study proposes to examine the coarticulation and feature-spreading characteristics of fingerspelling. A preliminary study identified feature categories to be examined. In keeping with these results and feature categories, three hypotheses were constructed: (1) anticipatory effects are more common than perseverative effects, (2) coarticulation is most prevalent word medially, rather than the word-initially or word-finally, and (3) larger articulators show spreading more often than smaller articulators and spread across multiple handshapes.

To test these hypotheses, five fluent ASL fingerspellers were recorded and the data was examined in reference to these three hypotheses. After analysis of this data, the first hypothesis was found to be supported. The second hypothesis was strengthened by this data. The third hypothesis developed from a simple division of large articulators versus small articulators into a complex hierarchy of features. These findings are discussed in terms of frequency patterns, physiological constraints, and spoken coarticulation models.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Signed languages have not been studied long compared to spoken languages, so many aspects of this language modality remain only vaguely described. This project aims to answer questions on how American Sign Language (ASL) fingerspelling is produced by looking at coarticulation patterns in this modality.

Coarticulation was first identified at the turn of the 20th century and was first named by Menzerath and de Lacerda in the 1930s (Hardcastle and Hewlett, 1999). Coarticulation has been described as "an overlapping of articulatory movements associated with speech sound segments" (Hardcastle, 2006: 501). Linguists' early descriptions of coarticulation presupposed that speech was then made up of "discrete phonological units" at some level (Hardcastle, 1999: 29). To more precisely describe coarticulation, the necessary features of these discrete units were categorized (as remains evident in any phonetics textbook), and the binary feature system became a mainstream idea. Coarticulation studies in many languages have attempted to identify common and universal patterns in how these features do or do not spread. These studies results have led to an adjustment in the understanding of coarticulation, from categorical features to continuous features and from single units to continuous units (Hardcastle and Hewlett, 1999: 13, 34, 43). Researchers have proposed various models to support the findings, which include a mixture of mental and physiological explanations.

ASL phonology may be a more recent area of study than English (or other spoken language) phonology, but it has the advantage of building on findings from spoken language. ASL has been shown to exhibit similar phonetic phenomena as spoken language, such as phonetic reduction and phonetic variation (Tyrone and Mauk, 2010), and it would make sense to search for similar coarticulation patterns in this medium.

Fingerspelling is a category of ASL signs made of 26 different handshapes. These handshapes are signed in sequence as an alphabetic representation. Studies imply that the duration of a fingerspelled word does shorten upon repetition within a single conversational exchange, leading to hypotheses of frequency effects (Wager, 2012). These studies show that we can expect to see the same types of frequency effects and reduction patterns (such as coarticulation) in signed languages as seen in spoken language studies.

The present study proposes to examine the phonetic coarticulation and feature-spreading characteristics of fingerspelling to provide a background for further work in fingerspelling processing. First, a preliminary study was done to identify which features could be readily examined. High-tech computer equipment, such as that used in other coarticulation studies (Jerde et al., 2003b), was not available for this project, so only visibly salient features were described and coded.

The preliminary study provided sets of coarticulating features to be categorized. Following these categories, three hypotheses were constructed:

(1) Anticipatory effects are more common than perseverative effects.

(2) Coarticulation is most prevalent in the middle letters of the word, rather than the beginning or end of the fingerspelled words.

(3) Larger articulators show spreading more often than smaller articulators and spread across multiple handshapes on either side of the articulated handshapes.

To test these hypotheses, five fluent ASL fingerspellers were recorded and the data collected was examined in reference to these three hypotheses.

After analysis, the data showed similar patterns as had been found in the preliminary study. The first hypothesis was supported by this data set. The second hypothesis was strengthened by this data, as will be discussed in the results below. The third hypothesis developed from a simple division of large articulators versus small articulators into a complex hierarchy of features, with some establishing more influence over other categories, as is being tested in English (Smits, 2001). The data from this study can be used to propose a possible hierarchy and as an indication of the frequency rates of these spreading categories.

BACKGROUND

Fingerspelling is a manual alphabet "used for verbatim representation of English words, phrases, or sentences…[and also] personal names, place names, names of months and holidays, and words for which no conventional signs yet exist" (Wilcox, 1992: 9). Fingerspelling is common for slang, abbreviations, or technical terms in which there is not an ASL equivalent or the exact English word is important for the context (Wilcox, 1992; Padden, 2005). There is also a category of words that are considered "stable" fingerspelled words or compound words—words that are in whole or in part consistently fingerspelled and are not lexicalized (Padden, 2005). Fingerspelled words are also loan signs or lexicalized signs (Padden, 1991; Wilcox, 1992). The category of fingerspelled words is eclectic and, as such, it is difficult to pin down exact numbers of fingerspelled signs. Approximately 6% of a corpus of ASL signs constructed by Morford and

MacFarlane consisted of fingerspelled words (Morford and MacFarlane, 2006). Another estimate taken from a corpus of short narratives is closer to 18% (Padden, 2005).

Often, fingerspelling is taught as a series of static shapes with a letter-to-letter correspondence with printed English letters (Hernandez, 1997; Padden, 2005). However, this perspective of fingerspelling is misleading. This is not how native signers have been shown to acquire this aspect of their language (Padden and LeMaster, 1985; Padden, 1991). Padden (2005) discusses how children begin to acquire the skill of fingerspelling much younger than they learn literacy (the first attempts are recorded around age 2), though the attempts often display errors just like other aspects of language acquisition. Wilcox (1992) also states how children perceive fingerspelling as just another "complex sign." After the English alphabet has been learned, native signing children relearn fingerspelling as a series of handshape–letter correspondences, perfecting the movements and handshapes (Padden, 2005). This pattern of acquisition seems to fit readily into Akamatsu's proposed "movement envelopes" (Akamatsu, 1983: 129). These movement envelopes change in overall shape based on the changes in handshape, and it is this overall shape that is perceived. Akamatsu's results show that children's productions, though using incorrect or incomplete letters, mirror adult movement envelopes (Akamatsu, 1983: 129). Examining this evidence for perception of fingerspelling as a whole is crucial in creating a new model.

A new model also needs to account for learning the "static hand configurations and the set of possible transitions" that come with fluency (Wilcox, 1992:20). The movement envelope model, which Wilcox expanded to a model of targets and transitions, suggests that fingerspelling can be seen as a series of movements, rather than static handshapes (Wilcox, 1992:29). Fingerspelling can then be seen as a series of goals and the movements between these goals. However, these movements between goals (or transitions) can be just as important as the static handshapes (or targets) and encode important and salient information, as demonstrated in Akamatsu's study discussed previously. In a fluent signer, these targets and transitions flow together so smoothly that it can be difficult for a nonexperienced signer to pick them out. Examining coarticulation should give some insight into the set of possible transitions and targets; these possibilities in turn should give insight into how fingerspelling is stored and processed.

In addition to questions of processing, there are also questions of how frequency may affect coarticulation. Spoken language studies have shown that high-frequency words undergo reduction more quickly than low-frequency words (Bybee, 2010). This tendency of high-frequency words to reduce also leads to entrenchment effects, which would be evident through patterns of coarticulation. However, finding an equivalent of this pattern in ASL is problematic.

Corpora of sign languages on the scale of spoken languages simply do not exist, so frequency is almost impossible to measure accurately. Researchers have relied on surveys of native speakers for frequency judgments on signs. For a fingerspelling project, frequency counts of words are even trickier. It is difficult to find reliable frequencies of proper nouns, brand names, and other frequently fingerspelled words in conversation. Simply using English word frequencies for ASL fingerspelled words will not work. A word may have an equivalent sign in ASL, but for purposes of clarification, emphasis, or grammar, the signer may choose to spell it out (Padden, 2005), or fingerspelling a word may be frequent in one context but not another. Frequency, then, needs to be counted as something else in signed languages, such as a particular set of combinations or motion "syllables" (Padden, 2005).

Few frequency reduction studies have been done in ASL, and reduction descriptions are not available for all the phonological parameters of ASL (handshape, location, and movement). However, studies have shown that location does reduce for ease of articulation (Tyrone and Mauk, 2010) and that high-frequency collocations reduce more than low-frequency collocations (Wilkinson, 2007). Preliminary studies also imply that the duration of a fingerspelled word shortens upon repetition within a single conversational exchange (Wager, 2012). These studies show that we should expect to see the same types of frequency effects and reduction patterns in signed languages that we see in spoken languages.

For this discussion of coarticulation of fingerspelling, the focus will be on the assimilation or dissimilation effects evident in the handshape. The other two phonological parameters of ASL, location and movement, have little variation in fingerspelling. Most examples of fingerspelling are articulated on the ipsilateral side of the body (Padden, 2005). This standard location for fingerspelling eliminates the variation signs may exhibit due to location. Also, movement is minimal compared to other signs. Aside from two fingerspelled letters (*J* and *Z*), movement is not specified and should not have a significant impact on the variation examined here. Variation in location and movement are exhibited by directional loan signs, but they will not be discussed in this study.

Coarticulation in handshape has been studied mainly out of an interest in how to create computer recognition software. Jerde et al. (2003b) have conducted studies employing high-tech equipment to measure variations in joint angles and articulation times for this purpose. These studies have been extremely specific, only cover a small set of fingerspelled letters, and view coarticulation in one of two ways: assimilation or dissimilation.

The purpose of this study is to provide a broader perspective on the trends of coarticulation in fingerspelling. This study will specifically examine where coarticulation occurs most frequently within a fingerspelled word (word-initial, word-medial, or word-final) as well as identify the most common features that spread between handshapes. The coarticulation described here will be mostly assimilation, or how the features from surrounding handshapes can be adopted by another handshape. After describing these aspects of coarticulation, I will fit these aspects into psychological and physiological frameworks to further explain these patterns.

PILOT STUDY

To establish that coarticulation does occur and to identify the measurements and features for further study, a small analysis examined a videotape of ASL fingerspelling. Each fingerspelled handshape was coded to determine whether it was articulated differently in different contexts and how these differences were reflected in the handshape.

Methodology

The data was a recording of 30 fingerspelled English words, which resulted in a total of 248 tokens (Table 1). The recording was done specifically to provide stimuli for an unpublished study several years ago. Due to this more formal register, these words should have less coarticulation than informal, conversational ASL fingerspelling.

Table 1: Words used in this study

English Word	
advertisement	pantomime
awkwardly	Philadelphia
bankruptcy	physics
baptize	pregnant
Cadillac	psychological
careful	pumpkin
chimney	rhythm
communicate	submarine
elaborate	surgery
funeral	third
graduate	tomato
helicopter	umbrella
hemisphere	vehicle
interrupt	video
mountain	vinegar

As these words were selected for a previous study, their selection was not particular to coarticulation. However, every English letter except *J, X,* and *Q* was represented at least once, providing a variety of token combinations for observation.

First, it was necessary to find features to describe the shapes of the fingerspelled words. Researchers have given different frameworks for handshape description (Lane, Boyes-Braem, and Bellugi, 1976 in Wilcox, 1992; Whitworth, 2011). The basic vocabulary for this project was based on Eccarius and Brentari's work on the Prosodic Model (Eccarius and Brentari, 2008: 78). In their study, Eccarius and Brentari describe a handshape coding system that could be used universally for all handshapes in all signed languages. This led to very detailed descriptions, as well as contrasts that were not necessary for this study. The first definition borrowed from their work was *selected* and *nonselected* fingers. Selected fingers are the fingers used to create the sign handshape, such as the index and middle fingers in the fingerspelled letter *U;* nonselected fingers are not an important part of distinguishing the sign from another sign, such as the ring and pinky fingers in a *U*. For selected fingers, features that are contrastive and applicable to ASL fingerspelling were used:

- *Extended*: the fingers are straight, away from the palm; "open" position
- *Flexed*: fingers are pulled in to the palm
- *Stacked:* extended fingers that are spread in varying levels, such as the letter "K"
- *Crossed*: extended fingers cross over one another, such as the letter "R"
- *Spread*: extended fingers are held apart

In this pilot study, I did not describe any characteristics of nonselected fingers, nor distinguish between primary and secondary selected fingers. A *bent* feature was added to distinguish a shape in between the *extended* and *flexed* features to account for rounded letters such as *C*.

I also added features for thumb placement:

- *Open*: out to the side of the hand, naturally resting away from fingers (*A*)
- *Bent*: a position where the joint is bent inwards toward the palm (*B, E*)
- *Lax*: a relaxed position, bent but moved forwards, rather than sideways (*C*)
- *Insert:* thumb is bent toward palm tucked between fingers (*T*)
- *Spread*: thumb pulls out and away from palm (*L*)

While there are many variations within each of these handshapes, I tried to reduce the number of different positions for this simple descriptive study. I anticipated that the results of the study would show that more or less distinction would be necessary within each category.

Four more features were necessary to describe fingerspelling. The first set described the position of the wrist, either *extended* (the upright position, forming a line from fingers to elbow) or *flexed* (the natural fall of the wrist). The second set of descriptors was to describe movement, either *supinating* (turning the palm from the receiver back toward the signer) or *pronating* (turning the palm from facing the signer to the receiver). These features provided enough distinctive features to begin coding the short video.

For each fingerspelled word, a target was identified that, for each token, most closely resembled the canonical handshape found on a fingerspelling card (Sternberg, 1998). I recorded the word, the frame, the number of selected fingers (excluding the thumb because it was coded separately), and the values for each of the above features. Each target took up multiple frames, so when choosing a frame, I aimed for the most canonical handshape before the hand began moving to the next letter. This was to catch the frame where a particular segment dominated the frame (Wilcox, 1992: 57) or was perhaps the only segment in the frame.

Results

The results of this study were that coarticulation did occur in the data set, even in this instance of careful fingerspelling. The features that carried over between the targets and the length of the carry-over depended on what could be considered the level of effort necessary for the signer to articulate the feature. I was able to organize these features into a hierarchy and use this as a basis for further investigation into coarticulation.

The feature at the top of the hierarchy was the pronation or supination of the wrist. Most letters are formed pronated, with the palm facing out towards the receiver. *G*, *H*, and *J* are the only letters that use a supinating motion in their canonical form, a rotation that moves the palm back toward the signer. This movement, however, is so large (in comparison with other articulatory movements) that it was seen in this study as both an anticipatory effect in the preceding segment and as a perseverative effect in the following segment. For example, in the word "hemisphere," the transition between the *S* and *P* show a very clear supination movement, though the actual requirement for supination does not occur until the next transition, directly before the *H*. The *P* is almost completely supinated to match a canonical form of the following *H,* and the supination (to return to the typical position of fingerspelling) carries over into the following *E*. Other tokens in the data set showed the same pattern, though the extension of the movement (spread over 1, 2, or 3 tokens) depended on the word. I would expect to see this pronating and supinating feature extend even further in online, casual fingerspelling.

Most fingerspelled letters are articulated with the wrist extended, the palm pronated. The letters *P* and *Q* are flexed downward, and the letters *H* and *G* are also flexed, though they are supinated and the distinction is not as visible. I expected the flexing and extending of the wrist to be a higher level of effort in the articulation of fingerspelled letters, and I expected it to have a similar spreading effect as the pronation and supination. However, I did not find the same extension of anticipatory or perseverative effects of the flexion in this small data set. A small trend in the data set was a slight carryover of the extension; the flexed letters in real-time fingerspelling are not flexed as far forward as their canonical counterparts. The small number of flexed letters

(2; *P* and *Q*) seems to prefer taking on the unmarked position (extension) rather than spreading the marked position (flexion).

Next, the placement of the thumb was a feature that consistently carried over between segments. I realized while coding the data just how much variation there was in the position of the thumb in the formation of the letters. For closed letters such as *O*, the thumb always touched the selected fingers and for letters such as *L,* the thumb always stayed spread out from the palm. Other letters, however, seemed to simply take on a similar thumb feature as the letter before it. For example, in the combination of *N-I*, the thumb is tucked under two fingers for the canonical *N* and is supposed to slip back out to my "open" position for the *I*. However, the data showed the signer tucking the thumb for the *N* and then leaving it tucked for the raising of the pinky into the *I* handshape. Similar to the thumb, the pinky finger is selected especially in the letters of *I* and *Y*. These two letters showed both perseverative and anticipatory effects.

The last area that showed consistent anticipatory effects was segments preceded by the letter *R*. *R* is the only letter in ASL that requires the middle finger to cross over the index finger. Preparation for this extra movement of the cross is consistently seen in the preceding letter as the middle finger begins to move before any other letter. This is especially apparent when *R* is preceded by an *E*. The preceding *E* in the data set was articulated with only the two fingers that will be used to articulate the *R*. Again, this may be due to the effort needed to get the middle finger higher or it may be due to physiological constraints.

Other features coded for did not provide as consistent or as notable effects as the five mentioned above. With the preliminary study, it was apparent the coarticulation was a phenomenon in fingerspelling, not just in ASL at large. With these five categories in mind (pronation/supination, flexion/extension, thumb placement, pinky placement, and the crossover), an experiment was developed to gather more coarticulation data.

HYPOTHESES

The results from the pilot study delineate the areas of coarticulation that could be further examined. Several features originally deemed as important were ignored during the further study in preference to other phenomena. Using the patterns described above, I formulated the following hypotheses to test during another fingerspelling study.

First, I hypothesized that anticipatory effects are more common than perseverative effects. Jerde et al. (2003b) found that anticipatory effects were more common in their sample than perseverative effects. In the pilot study, I did not carefully note which features showed more anticipatory or perseverative effects because I was mostly interested in identifying the features themselves. For the larger study, I determined to see if my findings would echo the previous study's results.

The second hypothesis is that coarticulation is most prevalent in the middle letters of the word, rather than the beginning or end of the fingerspelled words.

Finally, the third hypothesis was developed on the loose hierarchy found in the pilot study. It would seem that features that take more time or effort for the signer to articulate show spreading more often than other features and spread across multiple handshapes on either side of the articulated handshapes. Pronation and supination are considered the largest features for these studies, followed by the placement of the thumb and the crossover of *R*. Based on the results of the pilot study, wrist flexion/extension, pinky placement, and finger features were not expected to show a large coarticulatory effect, if any at all.

Participants

The participants in the study were five ASL signers: two males and three females. All participants were hearing and were at least 18 years of age. All participants had been signing for at least three years and used ASL professionally (e.g., an interpreter), privately (e.g., with family members), or both. Participants were asked to fingerspell as naturally as possible during their participation.

Methodology

Ten words were chosen from English that could demonstrate coarticulation from the prominent features described above.

Table 2: Words used in the experiment

advertisement
deliberation
epiphany
gumdrop
hemisphere
interrupt
predictable
quaking
rhythm
topographer

Four of these words were taken directly from the previously discussed pilot study. The rest were chosen based on the combination of letters that should produce favorable environments for observing coarticulation. The letters *F, J, W, X,* and *Z* were not included in favor of letters that had demonstrated coarticulation features in the pilot study. The letters were placed at the beginning, end, and middle of at least one word to give an idea of how placement in the word may affect the observed coarticulation.

The fingerspelling task was explained individually to the participants in English (a native language for all five participants), including the requirement of collecting data on film for analysis. Participants were told they could stop the filming at any time for any reason. Written consent was obtained, and all participants completed the task.

Participants were presented with each word and asked to fingerspell it three times as naturally as possible, with a slight pause at the completion of each word. The task took the participants an average of 2 minutes to complete. The fingerspelling was recorded on a handheld digital video recorder and only the dominant hand was captured.

RESULTS

The video recordings were analyzed and coded to examine which phonological features of ASL were being carried over between fingerspelled handshapes. Patterns will be qualitatively and quantitatively described here.

First, each token was examined as to whether it did or did not show coarticulation. For the purposes of this study, a token was coded as having undergone coarticulation if the canonical form of the handshape was altered due to its environment. Coarticulation was apparent during the transitions between tokens, but only coarticulation that lasted through the target of the surrounding tokens was considered included in the analysis. Handshapes articulated off the screen of the video or incorrect handshapes (e.g., substituting an *M* for an *N*, or switching a *B* and an *L*) were not included. Abnormalities in the production of a token that were not attributed directly to coarticulation (i.e., an *I* pinky when no *I* was present in the word to influence the token) were ignored. The data yielded 1,391 tokens. The number of tokens per letter is given in Table 3. Again, the words favored handshapes that had features that fell into the categories described in the pilot study and did not try to balance for frequency (in English or ASL).

Table 3: Number of tokens per letter in English words

A	89	N	74
B	29	O	58
C	15	P	119
D	58	Q	15
E	193	R	148
F	0	S	30
G	44	T	119
H	90	U	44
I	118	V	15
J	0	W	0
K	15	X	0
L	29	Y	30
M	59	Z	0

Coarticulation was categorized into one of six groups: effects of pronation/supination, flexion/extension, thumb, pinky, crossover, and fingers. The last group was added simply to examine whether coarticulation effects were found in the larger, more natural data sample.

The tokens were coded individually. A “#” marked tokens that were not articulated. A “0” was used for tokens that demonstrated no coarticulatory effects. “A” indicated a token that showed an anticipatory effect, or changes to the canonical articulation due to the following handshapes or handshapes. A "P" was used for tokens demonstrating a perseverative effect, or changes to the canonical articulation due to the preceding handshape or handshapes. "A/P" was used for letters that showed effects from both sides. The appropriate code was placed in the appropriate category of coarticulation for each token. The preceding handshape and the following handshape were included. The data yielded 64 nonarticulated tokens (4.6%), 805 non-coarticulated tokens (57.9%), and 521 coarticulated tokens (37.5%). The effects on a token could be found in multiple categories.

To check for objectivity in the study, a second coder examined a set of 109 tokens and coded following the described criteria. Cohen's Kappa for overall agreement was .7298 and agreement on type of coarticulation (anticipatory, perseverative, or both) was .6975. Reviewing the discrepancies, we found that a few of them were from tokens one of us had felt was not articulated, while the other felt it was simply a matter of degree of coarticulation. Additional discrepancies created a discussion on when *exactly* should be counted the "moment" of a token's completed articulation before the transition into the new handshape. It seems that this is a flaw of this experiment and that clearer decisions should be made to provide a stronger baseline for coding tokens. Revised coding brought overall agreement to .90. Regarding the agreement between anticipatory and perseverative decisions, the two raters had focused on different categories when making our decisions. One rater may have noticed a perseverative pinky while the other had focused in on anticipatory fingers. Again, this had a lot to do with which frames were considered the tokens and which the transitions. Agreement within the anticipatory and perseverative categories while making decisions about which feature category was impacted by coarticulation was much higher; the kappas were .94 and 1 for anticipatory and perseverative coarticulation respectively.

Hypothesis #1: Anticipatory and Perseverative Effects

The first hypothesis for this study was that anticipatory coarticulation effects occurred more often than perseverative effects. As stated above, 521 tokens were coarticulated with the preceding or following handshape. Of these, 277 tokens (53.2%) demonstrated anticipatory effects, 181 (34.7%) demonstrated perseverative effects, and 63 (12.1%) showed both. It would seem that, as a whole, anticipatory effects occur more often than perseverative effects.

Hypothesis #2: Coarticulation Location

The next hypothesis was that coarticulation was more common in the middle of the fingerspelled word than at the beginning or end of the word. This hypothesis was based on observations in the pilot study that the first and last letters of the word seemed prolonged. This may have been a factor of the environment of the filmed data for the pilot study, but it seems intuitive that a signer would articulate the first and the last letters of the fingerspelled word to indicate the word's boundaries. With this longer articulation, the effects of coarticulation would be smaller.

In the data for this experiment, 147 articulated tokens occurred at the beginning of the word and 145 articulated tokens occurred at the end. The remaining 1,035 articulated tokens occurred within the word. The difference in the number of articulated tokens is interesting to note between these two groups. Only four (1.4%) of the total number of possible beginning and end tokens (148 beginning tokens and 148 ending tokens) were nonarticulated. Three of the four were ending tokens. The middle tokens showed a larger number—approximately 5% of middle tokens were nonarticulated. This already gives tenuous support to the idea that the edges and the middles of the words are articulated differently.

The beginning token categories showed coarticulation in 16 tokens, and the ending token categories had coarticulation in 12 tokens, or 10.9% and 8.3% of the totals in the respective categories. Combining the categories gives an overall percentage of 9.5%.

The middle category shows percentage of coarticulation drastically different than the combined categories above. Of the 1,035 articulated tokens, 53% demonstrated coarticulation. Part of this difference could be attributed to the fact that these tokens have features on either side of them and this increases their chances of being coarticulated. However, even just taking the middle tokens demonstrating anticipatory effects and comparing this to the beginning tokens (which can only display anticipatory effects), still demonstrates a coarticulation percentage double the percentage of the beginning tokens. The middle tokens show anticipatory effects in 30.9% of tokens, compared to the above-mentioned beginning token percentage of 10.9%. The middle tokens demonstrating perseverative effects compared to the ending tokens show a similar, though not quite as drastic, difference (22.2% compared to 8.3%). Table 4 gives these percentages and Table 5 demonstrates how individual tokens were affected by their location in the word.

Table 4. Percentages of nonarticulated and coarticulated tokens by word location

	Total Number of Tokens	Percent of Tokens Nonarticulated	Percent of Tokens Coarticulated
Word Initially	147	.007	10.9
Word Medially	1,035	5	53.0
Word Finally	145	2	8.3

Table 5. Coarticulation effects by word location

	Number of Tokens Demonstrating Anticipatory Effects			Number of Tokens Demonstrating Perseverative Effects		
Letter	Word Initially	Word Medially	Word Finally	Word Initially	Word Medially	Word Finally
A	0	15	0	0	12	0
B	0	13	0	0	3	0
C	0	1	0	0	8	0
D	0	6	0	0	0	0
E	0	77	0	0	56	0
G	0	11	0	0	0	0
H	3	31	0	0	3	0
I	2	26	0	0	32	0
K	0	1	0	0	0	0
L	0	10	0	0	9	0
M	0	3	0	0	5	1
N	0	4	3	0	10	6
O	0	15	0	0	7	0
P	3	46	0	0	8	0
Q	3	0	0	0	0	0
R	0	11	0	0	35	1
S	0	6	0	0	4	0
T	5	31	0	0	14	1
U	0	8	0	0	15	0
V	0	8	0	0	0	0
Y	0	1	0	0	4	0
Total	16	324	3	0	225	9

*Handshapes can demonstrate both anticipatory and perseverative effects and may be counted in multiple categories.

These percentages and the data listed in Table 4 clearly demonstrate that coarticulation occurs more often in the middle of words than in the beginning or end of the word. This gives insight into what may be the most salient portions of a fingerspelled word—the beginning letter and the ending letter. These endpoints give the viewer necessary endpoints to select the proper word, even if coarticulation blurs some internal letters.

Hypothesis #3: Articulator Size

The pilot study seemed to give hints that features that were part of larger articulators (such as pronating on the forearm in the letter *G*) showed spreading more often than smaller articulators (such as the pinky in the letter *I*). The following sections will detail the varying levels and patterns of coarticulation found in the features selected for this study.

Pronation and Supination

Most fingerspelled letters are formed pronated, or with the palm facing the receiver. As stated before, only three handshapes (*G, H, J)* are supinated (with the palm facing the signer). In the pilot study, the large movement of pronation and supination, or the movement that involves turning the large articulators of the wrist and forearm, seemed to have the strongest effect on the surrounding handshapes.

The data sample for this experiment showed a similar effect. Approximately 26.1% of the total coarticulated tokens demonstrated coarticulation in this category. Of these 136 tokens, 58 (42.6%) demonstrated anticipatory effects and 78 (57.4%) demonstrated perseverative effects.

In this data set, the anticipatory effect of supination on pronated handshapes was found nearly exclusively on handshapes preceding an *H*. *H* occurred within a word for 85 tokens; 36 tokens, or 42%, influenced the directly preceding token, with the signer's palm turning in anticipation of the supinated handshape. In comparison, only 3 of the possible 30 tokens of *G* showed an influence to handshapes occurring directly prior to the token. These anticipatory effects were not limited to only one handshape prior to the supinated token. Four instances demonstrated anticipatory effects two handshapes prior to the supinated token: three occurred before an *H* and one occurred before a *G*. Though the number of this two-letter spread of anticipated supination is small, it does give evidence that the supinating movement has a substantial influence on the surrounding handshapes.

Supination showed even stronger perseverative effects. Approximately 51% of *H* tokens and 45% of eligible *G* tokens demonstrated perseverative effects on the tokens directly following them. The secondary spreading was also found on 15 tokens—over three times as common as the anticipatory effects. Though this is still a small sample size, the discrepancy between the anticipatory and perseverative effects of supination is still telling and raises questions. Is it easier to continue to articulate letters during the pronating movement than the supinating movement? Is it easier for the receiver to perceive distinct letters during pronation rather than supination? Regardless of this difference, the supinating feature, as one of the largest movements in the limited range of fingerspelling, spreads widely, reflecting the effort put into it by the signer.

It seems more common for the pronated letters to show supinating effects rather than vice versa. However, the pronated letters did affected supinated letters. For example, in one instance of *H*, the token occurred at the beginning of a word, following by an *E*. This token of *H* was articulated with the palm only partially turned toward the signer in anticipation of the pronating movement that would need to follow to articulate the *E*. Instead of the *E* showing the perseverative effects of the necessary supinating movement to articulate the *H*, the *H* showed anticipatory effects of the pronated *E*. Ten supinated letters in the data sample anticipated the following pronated letter by turning only part way. Only one supinated letter showed perseveration of pronation.

In fingerspelling, a supinating movement is a salient factor for signers in distinguishing words. As we have seen, the middle of fingerspelled words demonstrate more coarticulation, and this marked movement may spread to exaggerate this small set of letters from others.

Extension and Flexion

Like the movements of pronating and supinating, extension and flexion are done by the wrist and are used in ASL to distinguish between similar handshapes. Most ASL letters are signed with wrist extension. In the pilot study, I had expected that this movement (being done by a large articulator, the wrist) would also demonstration large coarticulatory effects. However, the careful signing and small data size prevented any conclusions being drawn about the effects of this wrist movement. As this feature is found on a large articulator, I again hypothesized that this feature would demonstrate significant effects, though slightly fewer effects than the supinating feature.

A total of 39 tokens (6.9% of total) showed anticipatory or perseverative effects in this feature category. The anticipatory and perseverative effects, however, seemed to be divided differently than the supination and pronation effects discussed before. The perseverative effects were nearly exclusively due to flexion (96%). For this data set, *Q* only occurred at the beginning of the word, but 27% of the tokens following this letter showed a perseverative effect of the flexing movement. *P* was more complicated, occurring at the beginning, middle, and end of words in the data set. The perseverative effect was much smaller, barely 9%. However, many of the *P*s occurred prior to *H*s, which can be articulated with a flexed wrist. Even if the letter is not articulated with the wrist flexed, the supinating movement would disguise any perseverative effects due to wrist flexion. When the *P*s followed by *H*s are excluded, the percentage of tokens with a perseverative effect due to wrist flexion rises to 15%.

Like pronation and supination, it seems that wrist flexion has the ability to affect tokens that do not directly follow a flexed handshape. This occurred for one token in the data set, the wrist flexion influencing a token two spaces away from the *Q*. It seems reasonable to believe that this effect would be seen more strongly in a larger sample, a different set of words, or faster fingerspelling.

The sample size is much smaller for strictly anticipatory effects for wrist flexion (6 tokens). One token demonstrates the anticipatory effect of the *P* two tokens ahead of the anticipated letter. There may be a physiological reason for this, perhaps that the muscle control in the wrist makes releasing to a flexed position quicker than bringing the wrist back to the extended position.

The remaining anticipatory effects were due to wrist extension. These are exclusively tokens of the letter *P* because of its distribution in the experimental words. Over half of the tokens demonstrating anticipatory effects showed anticipatory and perseverative effects of wrist extension. This is difficult to tease apart in this data set, as the tokens of *P* are surrounded on both sides by extended letters (e.g., *E, I, R*). Perhaps it is the combination of extended letters on either side of the flexed letter that create the effect of articulating the *P* closer to a canonical *K*, with the wrist extended rather than flexed. Only one word-initial token of *P* showed effects of wrist extension and no word-final tokens of *P* showed any extension. It seems that the extension effect needs to approach the flexed letter from both sides to be influential.

Thumb Placement

Thumb placement showed frequent anticipatory and perseverative effects, with 102 tokens (19.6% of total coarticulated tokens). Unlike other categories, these tokens demonstrated the effects evenly: 50% of the tokens showed anticipation and 50% showed perseveration. The variation in preceding and following letters was also much greater.

The thumb is used in many handshapes to complete the fingerspelled letter (e.g., D or *L*) or distinguish between letters (e.g., *N* or *T*). In these handshapes, the thumb placement is important and even crucial. Other handshapes do not use the thumb or allow various placements of the thumb. It is these handshapes that were influenced by the thumb placement.

The most common handshape to show thumb placement effects was the letter *I*. One-third of the tokens that demonstrated effects were of *I*, one of two letters that only require the pinky. The canonical handshape of an *I* dictates the other fingers and the thumb should be in a closed position, but *I* was highly influenced by the letters around it. Eight tokens demonstrated anticipatory effects on the thumb, coming before letters *B, S,* and *O*. These three letters use the thumb as an important part of their articulation and require the thumb to be brought to the front of the palm, instead of the side of the palm like the canonical *I*. This was consistent across the eight tokens. The 24 *I* tokens that demonstrated perseverative effects for the thumb feature were preceded by a variety of letters: *D*, *K, L, P,* and *T*. The *I* is a very quick letter to articulate, with only the movement of the pinky and the release the rest of the fingers into a "resting" position. However, the thumb does not seem to follow the same requirement of the other articulating fingers and it does not return to its canonical position for *I*. The thumb seems content to stay where it had been placed for previous letters without moving while the salient part of the *I* is articulated.

Thumb placement was also highly variable around the letter *O*. Even though the thumb is required to articulate this letter, it showed strong anticipatory effects, especially before the letter *N*. This appears to be because the thumb has simply moved through the required position for the *O* and gone to *N* without waiting to meet the fingers. The *ON* combination seems like it would be a frequent combination in fingerspelling, and the frequency of this combination may have led to the thumb highly anticipating the *N*.

In the example of the sequence *DROP*, the thumb placement hardly changes. It moves to the *bent* position to articulate the *D*. However, *R* does not require the thumb to be articulated, and the thumb seems to prefer to stay in the previous *D* (or upcoming *O)* position while the fingers articulate the *R*. The thumb is already in the correct position for the *O*, but hardly changes with the fingers articulate the *P*. This sequence demonstrates that the thumb prefers not to move, or prefers to move minimally, throughout fingerspelling.

This feature, however, is a difficult one to address any further for two reasons. First, the thumb has more degrees of freedom for movement than the fingers, allowing for many more possible placements than the fingers. Second, the results of this data set were extremely variable and make it difficult to draw firm conclusions. Few words showed consistent internal patterns and few letters show perseverative or anticipatory effects in substantial quantities. The overall trend, however, seems to be that thumb prefers minimal movement, only reaching various extremes in the letters for which it is required (such as *L*). This could be attributed to the fact that the thumb is the largest of all the fingers (if including physiology extending into the palm) and has the widest range of motion. This makes it a larger articulator than the others, which requires more movement from the signer. If the signer can ignore the canonical positions of the thumb, he or she has saved movement for the salient features of the letter being currently articulated, becoming a more efficient fingerspeller.

Pinky Placement

The pinky often moves independently from other fingers and is most notable by its absence in most letters. It is only salient by its presence in articulating two letters, *I* and *Y*. In this data set, 68 tokens showed coarticulation effects (13.1% of total coarticulated tokens). Like thumb placement, this category was split nearly evenly: 32 anticipatory effects and 36 perseverative effects.

In the anticipatory effects, 23 tokens (71.9%) were anticipating the pinky placement of *I* as the next letter. Four additional tokens were anticipating *I* two letters away. Two tokens anticipated *Y* as the next letter. This large percentage of anticipatory effects of pinky placement is can also be compared to the overall number of *I* and *Y* tokens. From 148 tokens of these two letters, 16.9% affect the immediately preceding letter. Letters with fingers drawn into the palm (*T*, *M*, and *L*) demonstrated anticipatory effects of these letters most frequently.

Perseverative effects were more significant; 30 out of 36 tokens (83.3%) were affected by a directly preceding *I* or *Y*. The letter *C* was particularly influenced by a preceding *I*. Nine out of the 15 possible *IC* combinations (60%) demonstrated a perseverative effect from the preceding *I*.

I is a fairly simple handshape to articulate, with only a small movement located in the pinky. This small movement also seems to make it easy to coarticulate, especially in combinations that include *TI* or *IN*. In those examples, neither the *T* nor the *N* need the pinky to articulate, so it seems easy to do a simultaneous coarticulation with the *T* or *N* articulated with the thumb, pointer finger, and middle finger, while the pinky is popped up. This combining of letters occurred in other environments, but it seemed particularly frequent for the pinky in *I*.

Articulating Fingers

This category was large (41.7% of total coarticulated tokens) and included a variety of patterns. I included this category to properly account for when and how often coarticulation was occurring. I did not delineate this category along the many different feature lines because that would be an exhausting study in itself. I will describe some general trends here for others to examine further.

First, I examined the *cross* feature of the fingers while articulating the letter *R*. Even in the small data set for the pilot study, this feature seemed to be highly anticipatory. Analysis of this larger sample upholds that conclusion. There are 148 tokens of *R,* and 85 (57.4%) showed coarticulation. Anticipatory effects were found in 80 out of the 85 (94.1%). Every letter that proceeded *R* showed anticipation for the crossover at least once, and the letter *H* showed anticipation of the crossover two letters prior to *R* in four tokens. This anticipation is usually shown by the noncanonical position of the middle finger; it is usually lifted higher than its typical position found in the canonical preceding letter. This is probably due to the physiological requirements for the cross. The middle finger has to lift and extend first to adjust properly behind the pointer finger. This necessity would cause the middle finger to want to get a head start during the articulation of a previous letter.

Another trend in the coarticulation noted in the articulating fingers is the adjustment of the number of fingers for coarticulation. For example, the letter *E* is highly susceptible to the number of fingers being used in the letters articulated before and after it. Depending on these letters, the data shows *E* being articulated with two, three, and four fingers. In the word *advertisement, E* is between two letters, *V* and *R,* that are articulated with two fingers. Approximately half of the tokens of *E* in this environment were articulated with only two fingers. *E* also follows this assimilation trend even if the influence is coming unevenly from either direction: *TER*, *SEM*, *HEM*, and *BER*. The letter *H* also demonstrated a change in number of articulating fingers when followed by *M*.

The angles of the fingers during articulation also changed frequently. A previous study examined this in two specific strings of letters: *ISC* and *NTR* (Jerde et al, 2003b). Their work detailed the angles of these letters based on varying fingerspelled environments and described the variations in 17 different joint angles. While the coding in this study is not nearly as detailed, the same assimilation and dissimilation trends could be observed in the finger angles. In the combination of *DVE*, the angle of the fingers in the V were out and slightly bent, as the pointer finger lowered towards the upcoming *E*, rather than straight up and down. In this case, *V* is assimilating in articulation to the letters on either side. Dissimilation can be found in the sequence *UMD,* where the curve of the middle, ring, and pinky fingers are in an exaggerated curve to distinguish from the curled-up *M* just articulated. Dissimilation could also possibly explain the abnormalities in production that were excluded from this study that could not, at first glance, be attributed to coarticulation in its environment.

It is apparent that articulating fingers are susceptible to many patterns of assimilating and dissimilating to surrounding elements in their environments. More detailed study (and more advanced measuring techniques) will hopefully provide more specific patterns for the coarticulatory changes found in fingerspelling.

DISCUSSION

The above results have demonstrated some important trends about coarticulation in ASL fingerspelling. First, it was demonstrated that, as a whole, anticipatory coarticulation effects are more common than perseverative effects. This may be due to the temporal nature of language—each movement must take place in time, following and preceding another movement. Anticipating the movement in the following moment, rather than looking back at previous moments, may account for this trend. Anticipatory coarticulation in spoken languages was explained through the “look ahead” model, which was supported by several studies (Hardcastle and Hewlett, 1999: 43). This model states that coarticulation occurs because the individual is anticipating features that will be coming in future phonemes and begins moving articulators in preparation. However, Hardcastle and Hewlett (1999) provide several criticisms for this perspective, including the complex system necessary to decide which and how far binary features spread. Possibly a better explanation would be one of coproduction, explained by Fowler and Saltzman (1993). Coarticulation is described as a series of intergestural overlaps, waxing and waning in smooth arcs through time. These arcs, called “activation waves,” are dependent on how much of the articulatory space the phonemes share and how long the phoneme can exert its maximum influence on articulators (Fowler and Saltzman, 1993: 183). This provides an explanation for why both anticipatory and perseverative coarticulation occurs, as each phoneme follows a natural pattern of movement. This model, though conceived for spoken languages, seems to transfer well to the manual modality. Viewing fingerspelling recordings in slow motion provides the perspective necessary to see the smooth transitions between phonemes as each handshape receives a short moment in time as the maximally influential phoneme in the articulatory space. More study needs to be done to pin down how these activation waves can be described and measured in ASL and if this explanation is viable in this medium.

Second, coarticulation occurs with letters in the middle of the word much more frequently than the letters at the beginning or end of the word. Over half of the tokens that occurred in the middle of the word demonstrated coarticulation, while the tokens found on the word boundaries were coarticulated much less (Table 4). This supports the idea that a movement envelope is salient to the receiver of the sign and that the initial and final letters are crucial to the fingerspelled word. This explanation is supported by patterns of loan signs in ASL. Toy, bus, and park are English words that have been borrowed into ASL. The fingerspelled words of T-O-Y, B-U-S, and P-A-R-K have become T-Y, B-S, and P-R-K. These lexicalized forms preserve the first and last handshapes and "invariably" word-medial handshapes have been allowed to reduce or to delete completely (Battison, 1978; 142). Further work in examining reduction, frequency, and coarticulation patterns may give insights into why this may be.

The third hypothesis demonstrated much more complexity than the other two. The hypothesis was that larger articulators take more time and effort to move, which would impact the surrounding letters more than the smaller movement and effort required for smaller articulators. This would lead to a kind of hierarchy in the breakdown of how frequently types of coarticulation could be found. Strictly looking at the number and percentages of tokens in each of these categories for this data, however, is misleading.

According to my hypothesis, pronation and supination should be the most frequently coarticulated features and should be the category with the highest percentage of the total coarticulated totals. Instead, the large and eclectic category of finger features has the highest percentage of coarticulated tokens (41.7%). However, not every token could possibly demonstrate effects from pronation and supination because only three letters contain this feature, whereas every letter in the sample set could potentially have an effect of coarticulated finger features.

To give a more accurate idea of how frequently each category of coarticulation occurs, a rough estimate of the number of possible tokens that could demonstrate coarticulation for these features was found. Taking the total number of tokens that show coarticulation and dividing it by this rough estimate produced new percentages of coarticulated features (Table 5). These new percentages provide numbers that seem to be closer to what was observed. The pronation and supination affected the majority of the estimated possible tokens that could demonstrate this feature. The *R* crossover also proved to be a highly influential feature. Surprisingly, the placement of the pinky was the third most common in the rough estimate category, affecting nearly a quarter of adjacent tokens. Extension and flexion follow with approximately 17.3% of possible coarticulated tokens affected, while finger features and thumb placement follow well behind these other categories.

Table 6. Tokens by category

Category	Total Tokens	Total Estimated Possible Coarticulated Tokens**	Percent of Estimated Possible Coarticulated Tokens
Pronation/Supination	136	225	60.4
Extension/Flexion	39	225	17.3
Thumb Placement	102	2,520	4.0
Pinky Placement	68	270	25.2
Crossover	85	270	31.5
Finger Features	217	2,520	8.6

**Estimated possible coarticulated tokens were found by counting each word-medial token twice and each word initial and word final token once for the tokens that could be influenced by properties of the token.

While this pattern does fit into my hypothesis more than just comparing the raw numbers of coarticulated tokens, it was still not what was expected. It seems the physiological explanation of more effort or time leads to more feature spreading only seems to satisfactorily explain the pronating and supinating movement. Wrist flexion and extension can be partially attributed to this, though the coarticulation seemed to affect the extended letters into remaining flexed. Signers in this data set seem to prefer to discard the harder movement (or simply the marked movement) rather than allow it to spread across features.

Also, considering the preference of the thumb to stay where it was placed previously, it would seem that it would also show more coarticulation than it did. However, this may have something to do with the letters that it is selected for in articulation. Some signers were more conscientious of selecting the thumb for certain letters than others (e.g., being more particular about thumb placement for *R* or *P*). This coarticulation feature may be something that may disappear in a larger data set.

The pilot study also didn't seem to give any indication that pinky placement would be a feature that would tend to be coarticulated. However, it does make sense in the fact that the pinky is frequently either nonselected or articulated separately than other fingers. It would be easy to anticipate or continue to articulate the *I* or the *Y* while the fingers that are more often selected for articulation formed the surrounding letters. This was found in the data in combinations such as *TI*, *DIC*, or *ION*. Faster fingerspelling would probably accentuate this pattern.

The finger features category deserves a much closer look than was given here. With so many internal features and influence on both sides, the letters in the middle of the words (most often distinguishable by finger placement) should be a rich place to examine what are the most salient features. Findings by Jerde et al. (2003a) demonstrate that it is possible that as few as four joint angles are necessary to produce the majority of ASL fingerspelled letters. The joint angles vary, even in similar letters (*I* and *S*), demonstrating the biological constraints on the formation of the handshapes; additional findings should provide evidence of biological constraints on finger coarticulation as well.

The hierarchy features of large articulators having more coarticulation than small articulators does not hold up in this data set; these findings have demonstrated important trends in fingerspelling. There is obviously an effect from the size of the articulator. While the articulators are not so easily placed in a hierarchy as I had believed, the large movements of the forearm and the wrist do have a significant impact on the letters surrounding them. These movements are very salient to the receiver and are necessary for the distinguishing of words.

It also seems probable that these patterns of coarticulation could be explained by frequency. As discussed before, it is virtually impossible to estimate the frequency of ASL fingerspelled words accurately, but other perspectives could provide answers. Padden suggested examining fingerspelled words in terms of "syllables" based on movement, e.g., BANK would have two syllables of movement: B-A and N-K (Padden, 2005). This syllable approach may allow for a better study of frequency effects in the articulation of the fingerspelled letters. Padden's example of BANK is another lexicalized loan sign, denoted as #BNK or #BK. The frequency of the B-A syllable may have led to reduction to a simple B (keeping with the second hypothesis above) and the N-K may currently be undergoing reduction (which may explain the alternative forms). The syllable approach and this explanation of #BNK is just one possible explanation. However, the application of Padden's suggestion to my data does provide insight into the observed coarticulation patterns. *I* was coarticulated more frequently in the combination of *TI* (13 out of a possible 30 combinations; 43%) than in the combination of *KI* (1 out of a possible 15; 6.7%). *R* also demonstrated more anticipatory effect in *ER* (70.7%) than the more infrequent *DR* (13.3%). A more controlled study of frequent combinations could provide more insight into the possibility of coarticulation, and even reduction, due to frequency.

CONCLUSION

This study's purpose was to provide evidence that coarticulation occurred more frequently in the middle of words and that anticipatory coarticulation occurred more frequently than perseverative coarticulation. Along with these conclusions, this study described five categories of features that showed coarticulation and their respective frequencies found in this data. Pronation and supination coarticulation effects were the most prevalent. Coarticulation that included anticipating or continuing the movement of the pinky was the next most common. Wrist extension and flexion were also shown to be important features that spread word internally. While coarticulation was definitely present in thumb placement and finger features, these were both large categories that require further study before definite conclusions can be drawn on their respective patterns.

The trends detailed in this study seem to be able to be described by biological constraints (e.g., the movement of larger articulators takes more time and effort than smaller ones) or by a possible frequency effect. Additionally, a closer look at the application of coproduction or other coarticulation models to fingerspelling may provide an explanation for articulatory gestures. Further study could include an examination of coarticulation trends at different rates of fingerspelling, different combinations of handshapes (possibly controlled for frequency), and differences between native and non-native signers. These studies could all provide insights into the psychological and phonological processes that are part of fingerspelling production. It is clear there is a lot of work to do to completely describe the production of coarticulation in ASL fingerspelling and how this contributes to communication.

REFERENCES

Akamatsu, C.T. (1983) Fingerspelling formulae: a word is more or less the sum of its letters. *Proceedings of the III. International Symposium on Sign Language Research, Rome, June 22-26 1983*, Siler Spring: Linstok Press, Inc., 126-132.

Battison, R. (1978) *Lexical borrowing in American Sign Language*. Silver Spring: Linstok Press, Inc.

Bybee, J. (2010) *Language, usage, and cognition*. New York: Cambridge University Press.

Eccarius, P. and Brentari, D. (2008) Handshape coding made easier: A theoretically based notation for phonological transcription. *Sign Language and Linguistics,* 11(1), 69-101.

Fowler, C.A. and Saltzman, E. (1993) Coordination and coarticulation in speech production. *Language and Speech,* 36(2, 3), 171-195.

Hardcastle, W.J. and Hewlett, N. eds. (1999) *Coarticulation: theory, data, and techniques*. New York: Cambridge University Press.

Hardcastle, W. (2006) Coarticulation. *Encyclopedia of Language and Linguistics,* edited by K. Brown; Elsevier Science, 501.

Hernandez, R.A. (1997) Teaching fingerspelling: The role of transfer of learning strategies, serial ability, and self-efficacy. Unpublished dissertation. University of Connecticut.

Jerde, T.E., Soechting, J.F., and Flanders, M. (2003a) Biological constraints simplify the recognition of hand shapes. *IEEE Transactions on Biomedical Engineering*, 50(2), 265-269.

Jerde, T.E., Soechting, J.F., and Flanders, M. (2003b) Coarticulation in fluent fingerspelling. *The Journal of Neuroscience*, 23(6), 2383-2393.

Morford, J.P. and MacFarlane, J. (2003) Frequency characteristics of American Sign Language. *Sign Language Studies*, 3(2).

Padden, C.A. (1991) The acquisition of fingerspelling by deaf children. *Theoretical Issues in Sign Language Research*, edited by P. Siple and S.D. Fischer; The University of Chicago Press.

Padden, C.A. (2005) Learning to fingerspell twice: Young signing children's acquisition of fingerspelling. *Advances in the Sign Language Development of Deaf Children*, edited by B. Schick, M. Marschark, and P.E. Spencer; Oxford: Oxford University Press.

Padden, C.A. and LeMaster, B. (1985) An alphabet on hand: the acquisition of fingerspelling in deaf children. *Sign Language Studies,* 47, 161-173.

Smits, R. (2001) Evidence for hierarchical categorization of coarticulated phonemes. *Journal of Experimental Psychology: Human Perception and Performance,* 27(5), 1145-1162.

Sternberg, M. L.A. (1998) *American Sign Language Dictionary,* 3rd ed., HarperPerennial.

Tyrone, M.E., and Mauk, C.E. (2010) Sign lowering and phonetic reduction in American Sign Language, *Journal of Phonetics*, 38, 317-328.

Wager, D.S. (2012) Fingerspelling in American Sign Language: A case study of styles and reduction. Unpublished thesis. University of Utah.

Whitworth, C. (2011) Features and natural classes in ASL handshapes. *Sign Language Studies*, 12(1), 46-71.

Wilcox, S. (1992) *The phonetics of fingerspelling*. Philadelphia: John Benjamin Publishing Company.

Wilkinson, E. (2007) Finding frequency effects in usage of NOT collocations in American Sign Language. Unpublished manuscript