Synchronic Handshape Variation in ASL: Evidence of Coarticulation

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0. Introduction

Past research has noted patterns of variation in the major articulatory parameters of sign formation in American Sign Language (Klima & Bellugi 1979; Wilbur 1987; Liddell & Johnson 1986, 1989; Sandler 1993).[1] Handshape – the distinct shape produced by extension and/or flexion of the finger and thumb joints – is one of the major parameters of sign formation (Stokoe 1960). A change in the handshape parameter can result in a change in the meaning of a sign. In fact, there are many sets of minimal pairs of signs that differ only in handshape.

The literature on ASL presents cases in which handshape varies as a function of the handshape of a neighboring sign (Klima & Bellugi 1979; Wilbur 1987; Liddell & Johnson 1986, 1989; Sandler 1993b). These observations are similar to descriptions of assimilation and coarticulation in the speech literature in that such patterns in speech are also context sensitive. The discussions of handshape variation can be divided into two major cases: variation in the dominant hand and variation in the nondominant hand. The dominant, or active, hand is the hand used in one-handed signs. Handshape variation found in the dominant hand involves the specification for the handshape of one sign

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[1] American Sign Language, or ASL, is the manual-visual language used by between 200,000 and 500,000 deaf people in the United States and parts of Canada. As research since the 1960's has shown, ASL is a separate language, distinct from the spoken language of the surrounding community (Klima & Bellugi 1979).

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being blended with, or being completely replaced by, the handshape of a neighboring sign (Liddell & Johnson 1989, Wilbur 1987). The nondominant, or inactive, hand is only used in two-handed signs. Variation in the nondominant hand is most often observed in compounds as the result of historical change (Wilbur 1987, Sandler 1993, and Liddell & Johnson 1986). This type of variation occurs when a relaxed hand that is not used in the production of a one-handed sign anticipates or perseverates the handshape of an adjacent two-handed sign.

The purpose of this paper is to examine handshape variation in both the dominant and nondominant hands with the goal of classifying the observed variation as gradient or categorical. A gradient pattern would show effects only at the edges of the sign (i.e. phonetic coarticulation); while a categorical pattern would show effects throughout the entire sign (i.e. phonological assimilation) (c.f. Cohn 1993). In addressing this distinction, I also test whether rate of signing conditions handshape variation. Although rate has been shown to affect coarticulation (Gay, 1978), it is presumed to not affect phonological processes (Myers, in press). Through a series of experiments that utilize an instrumental approach to sign language research, I argue that most of the synchronic handshape variation found in ASL is characteristic of phonetic coarticulation, not phonological assimilation.

1. Methodology

1.1. Participants

The research for this study was conducted in Austin, TX with four native signers of ASL. All participants were raised by deaf parents and had acquired ASL naturally from birth. All participants were also right-handed. Thus the right hand was the dominant hand for these signers.

1.2. Stimuli

Two distinct handshapes were examined in both the dominant and nondominant handshape experiments. These handshapes are 5hand and index. The 5hand is produced by extending all the fingers and thumb and spreading them apart. This handshape is similar to the gesture for the number five. The index handshape is produced by extending the index finger and curling all other fingers to the palm. This handshape is often used in pointing gestures. These handshapes were chosen because they are two of the six most frequently occurring handshapes in ASL and because they are not easily confused (Klima & Bellugi 1979). By using distinct handshapes, I am able to detect handshape variation more easily than if similar, or highly confusable, handshapes were used.

The stimuli were comprised of sequences of two signs as can be seen in (1). Each sign was specified for one of the handshapes discussed above and was signed within the carrier phrase *TYPE* _____ *TYPE*. This carrier phrase was chosen because TYPE is a two-handed sign produced with a somewhat bent 5hand as in the gesture for typing. For this handshape, the fingers are neither fully extended (5hand) nor contracted (index) as when the hand is fisted. The carrier phrase and the focus sequences were printed on cue cards

with ASL glosses (English words in all capital letters that represent ASL signs). Each sequence was made up of a modifier and a head and adhered to the grammar of ASL as judged by a native ASL consultant.

(1) The Stimuli -- Bolded signs indicate the signs under analysis.

Dominant Hand Experiment		**Nondominant Hand Experiment**	
Index-Index	*Index-5hand*	*Index-Index*	*Index-Relaxed hand*
TRUE SMART	**TRUE** MOTHER	**TRUE** SMART	**TRUE** DIFFERENT
FAKE SMART	**FAKE** MOTHER	**FAKE** SMART	**FAKE** DIFFERENT
Index-Index	*5hand-Index*	*Index-Index*	*Relaxed hand-Index*
SMART **TRUE**	MOTHER **TRUE**	SMART **TRUE**	DIFFERENT **TRUE**
SMART **FAKE**	MOTHER **FAKE**	SMART **FAKE**	DIFFERENT **FAKE**

The signs used in the dominant hand experiment were chosen because they are all produced with either an index handshape or a 5hand. TRUE, FAKE, and SMART are index signs, and MOTHER is a 5hand sign. Index-Index sequences provided control cases for Index-5hand and 5hand-Index sequences. The signs used in the nondominant hand experiment were chosen because they are all produced with index handshapes. TRUE, FAKE, and SMART are one-handed signs, and DIFFERENT is a two-handed sign. The sequences of one-handed signs are produced with relaxed handshapes in the nondominant hand, and the one-handed/two-handed sequences have a relaxed nondominant hand followed or preceded by an index handshape.

In addition to varying the handshape juxtapositions, the rate at which the participants produce the elicited phrases was also varied. The stimuli were randomly ordered for each participant and presented in 20 blocks during a single experimental session. Participants were asked to sign half the blocks at a normal rate and the other half as fast as s/he could (12 sequences x 10 blocks x 2 rates = 240 trials).

The signing was recorded using one video camera and five infrared-sensitive cameras (Vicon System 250 from Oxford Metrics), each equipped with an infrared strobe around the lens. Prior to recording, reflective spheres were attached to the signers' wrists and the tips of her/his pinkies; the distance between these points represents pinky extension, which is one way to differentiate an index hand from a 5hand or a relaxed hand (henceforth H0).

1.3. Coding

The frames that marked the onset, midpoint, and offset of the movement of index signs were recorded. Data on the onset and offset were examined because they should shed light on effects that occur at the edges of signs. Data from the midpoint of the signs may reveal whether effects noted at the edge actually persist throughout the sign.

Sign movements were identified by reference to the ends of their movement trajectories. This approach to identifying the movements of the signs was used because the ends of the movement trajectories were easy to identify using the kinematic data.

This method provided a non-arbitrary way of identifying sign endings; intercoder agreement for determining the ends of the movement trajectories was highly reliable (93%). For the analyses presented in this study, the beginning of a following sign is seen as occurring immediately after the end of a preceding sign. This approach to identifying sign movement differs from other sign researchers who view the sign stream as a sequence of lexical sign movements and transition movements (Liddell 1984, Sandler 1993, Brentari 1998). Because of the problems in identifying the lexical movements of a sign using the kinematic data and because I am interested in any variation that may be found during the movements that have been traditionally classified as transition movements, I coded sign movements as movements that abut one another in the sign stream.

The beginning of the movement for a given sign was identified as the frame after the end of the movement of the preceding sign. The midpoint of the movement was calculated as the frame representing the numeric middle between the beginning and end of the sign.

At each of these timepoints – beginning, middle, and end of the sign movement-- the extension of the pinky was recorded. Pinky extension was represented by the distance between the reflective spheres on the signer's wrist and pinky and was calculated in millimeters by the Vicon program. These measurements were taken for both the dominant and nondominant hands. A small measurement would be indicative of an index handshape, in as much as the pinky is bent toward the palm, and a larger measurement would indicate a 5hand or a relaxed hand as the pinky is somewhat extended.

Because some participants had larger hands than others, the raw measurements of pinky extension could not be pooled for analysis. Instead, each individual's measurements were converted into z scores. A z score denotes how many standard deviations above or below the mean a value falls. The mean of a set of z scores is always zero. Once each participant's data had been converted to z scores, these normalized scores were pooled for analyses. All analyses reported in this paper were conducted using the normalized z scores from all four participants.

2. Handshape Variation in the Dominant Hand

During the articulation of a sign, the dominant hand is always specified for a particular handshape. Variation in the dominant hand is seen when the handshape of one sign is blended with the handshape of an adjacent sign. In the following two experiments, I test whether anticipatory and perseverative effects of handshape variation are present in ASL.

2.1. Index Sign in First Position

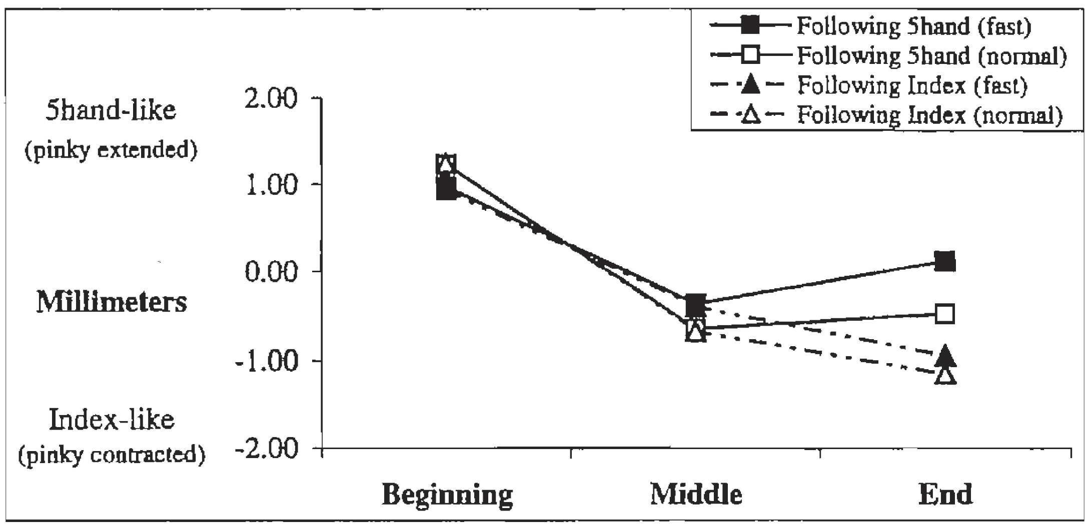
The experiment focusing on index signs in first position asked whether anticipatory coarticulation is present in ASL by examining index signs that were followed by either another index sign or by a 5hand sign. This experiment addressed two main questions: Is the index handshape produced differently when *followed* by another index handshape

compared to its production when followed by a 5hand sign? And if a difference is found, is it affected by rate of signing? The means and standard deviations of the z pinky extension scores in each of the conditions analyzed are given in (2). These means are graphically represented in (3).

(2) Pinky Extension Z Score Means (SD) for Index in First Position

	Position in Index sign		
Following environment	**Beginning**	**Middle**	**End**
Following 5hand sign, fast	0.98 (.41)	-0.37 (.44)	0.12 (0.88)
Following 5hand sign, normal	1.23 (0.46)	-0.65 (0.42)	-0.48 (0.87)
Following index sign, fast	0.94 (0.49)	-0.40 (0.38)	-0.95 (0.43)
Following index sign, normal	1.25 (0.50)	-0.68 (0.49)	-1.15 (0.42)

(3) Pinky Extension of Index Signs in First Position: Dominant Hand Mean Z Scores



In the figure above, the smaller the value on the y-axis, the more contracted the pinky, and thus the more index-like the handshape. The larger measurements at the beginning of the sign are most likely due to the handshape of the preceding sign, TYPE, which is produced with a 5hand-like handshape. A separation between the dark and light symbols may indicate an effect of rate, and a separation between the squares and triangles would suggest an effect of the handshape of the following sign.

In order to determine whether the different conditions actually caused significantly different handshapes to be produced, a repeated measures Analysis of Variance (ANOVA) was performed using data from all four participants. The pinky extension z scores served as the dependent measure, and the independent variables were

position within the sign (beginning, middle, or end), handshape of the following sign (index or 5hand), and rate of signing (normal or fast).

The results of the ANOVA support the tendencies observed in (3). Although main effects of position within the sign ($p<.001$), handshape of the following sign ($p<.001$), and rate ($p<.001$) were found, the significant three-way interaction of the handshape of the following sign with rate and position, $F(2, 974) = 3.340$, $p<.036$, forces us to look deeper than the main effects in order to describe a complete picture of the handshape variation. Bonferroni post hoc analyses of the three-way interaction revealed that the differences due to the handshape of the following sign were significant only at the end of the sign ($p<.001$). This effect of following sign was greater at the faster rate of signing such that the most 5hand-like handshapes were produced preceding a 5hand sign at a fast signing rate, and the most index-like handshapes were produced preceding another index sign during a normal signing rate.

The end of the sign proved to be susceptible to anticipatory handshape effects. Not surprisingly, this position within the sign is closest to the conditioning environment. Effects of following sign were not observed in the middle of the sign or at the beginning. These results show a gradient effect of following handshape, indicating that this variation is due to anticipatory coarticulation. Further evidence for a coarticulatory account is found in the greater effect of following handshape at the faster rate.

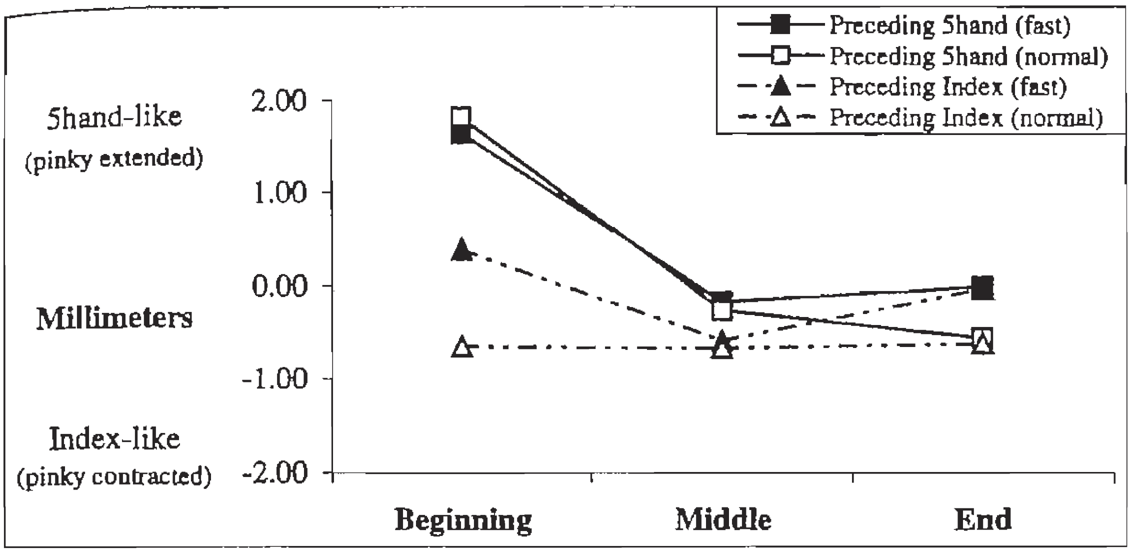
2.2. Index Sign in Second Position

In order to determine whether perseverative coarticulation also occurs in ASL, index signs preceded by either another index sign or by a 5hand sign were analyzed. This experiment also addressed two main questions: Is the index handshape produced differently when *preceded* by another index handshape compared to its production when preceded by a 5hand sign? And if a difference is found, is it affected by rate of signing? The means and standard deviations of pinky extension z scores in each of the conditions under investigation are given in (4), and these means are graphically represented in (5).

(4) Pinky Extension Z Score Means (SD) for Index in Second Position

	Position in Index sign		
Preceding environment	**Beginning**	**Middle**	**End**
Preceding 5hand sign, fast	1.65 (0.32)	-0.17 (0.52)	-0.01 (0.68)
Preceding 5hand sign, normal	1.82 (0.44)	-0.26 (0.53)	-0.56 (0.41)
Preceding index sign, fast	0.39 (0.71)	-0.59 (0.29)	-0.03 (0.80)
Preceding index sign, normal	-0.65 (0.62)	-0.67 (0.32)	-0.62 (0.40)

(5) Pinky Extension of Index Signs in Second Position:
Dominant Hand Mean Z Scores



Again, the smaller the value on the y-axis, the more contracted the pinky, and thus the more index-like the handshape. The fairly large separation between the squares and triangles at the beginning of the index sign indicates that the handshape being produced appeared more index-like when the preceding sign was another index sign compared to when it was a 5hand sign. This tendency seems to carry-over into the middle of the sign as well, although to a lesser extent. At the end of the index sign, there is a clear separation between the dark and light symbols, suggesting that more 5hand-like handshapes were produced at the faster signing rate. This result could be due to phonetic undershoot during fast signing.

In order to determine whether the observed differences were significant, a repeated measures ANOVA was performed using pinky extension z scores from the signs in second position as the dependent measure. The independent variables were position within the sign (beginning, middle, or end), handshape of the preceding sign (index or 5hand), and rate of signing (normal or fast).

The results of the ANOVA include significant effects for each of the independent variables ($p<.001$). Thus, handshapes produced at a fast rate tended to be more 5hand-like than those produced at a normal rate, and handshapes produced after a 5hand sign tended to be more 5hand-like than those produced after another index sign. A significant three-way interaction of preceding handshape with rate and sign position was also found, $F(2, 974) = 4.506$, $p<.011$. Post hoc analyses reveal that the effects due to preceding sign were significant both at the beginning ($p<.001$) and middle ($p<.001$) of the index sign. In these positions, the preceding sign affected the index handshape such that the handshape produced perseverated the handshape of the preceding sign. The differences attributable to rate of signing were significant at both the beginning ($p<.026$) of the sign and at the end ($p<.001$), but not in the middle. At the end of the sign, a faster rate created a more 5hand-like handshape regardless of preceding sign. At the beginning of the sign,

the interaction of rate with the handshape of the preceding sign was significant. When an index sign preceded, the faster rate created a more 5hand-like handshape ($p<.002$), but when a 5hand sign preceded, the faster rate caused a more index-like handshape ($p<.026$). These results could be due to articulatory undershoot during fast signing in that neither the preceding index handshape nor the preceding 5hand achieve their target pinky extensions during the preceding sign. Yet these results are surprising because they are contrary to what would be expected if a faster rate increased the coarticulatory effects of the preceding sign.

In this experiment, the beginning of the index sign was closest to the conditioning environment of the preceding handshape and proved susceptible to perseverative effects. Interestingly, the perseverative effects persisted into the middle of the sign. Because they do not continue to the end of the sign, the effects appear to be gradient and indicative of coarticulation. Although coarticulation is expected to increase during fast signing, this expectation was not born out in the data. Instead, the coarticulatory effects of the handshape of the preceding sign seem to be dampened during the faster signing rate. Further research is needed in this area to fully understand why a faster rate appears to decrease perseverative handshape coarticulation.

3. Handshape Variation in the Nondominant Hand

I now turn to the experiments conducted on the nondominant hand. During the articulation of a one-handed sign, the nondominant hand (i.e. H0) typically exhibits a relaxed handshape that is not part of the inventory of ASL handshapes. Thus during a one-handed sign, the nondominant hand is unspecified for handshape. The coarticulation literature shows that unspecified articulators are more susceptible to coarticulatory effects than specified articulators (Daniloff & Hammarberg 1973, Kent & Minifie 1977). Therefore, a high level of coarticulation may be likely in the nondominant hand. During a two-handed sign, the nondominant hand takes on the handshape specified in the lexicon for that sign.

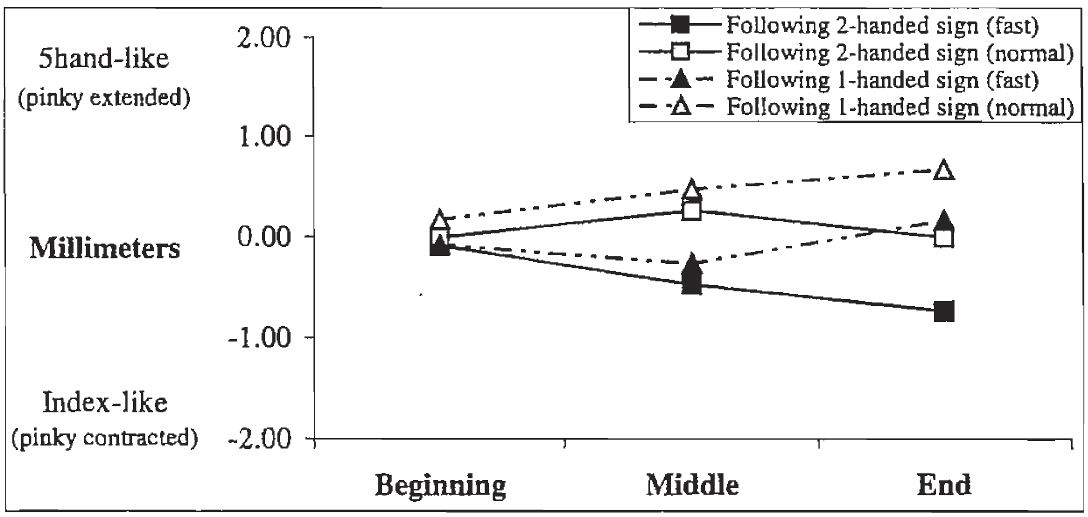
3.1. One-Handed Sign in First Position

In order to determine whether anticipatory coarticulation occurs in the nondominant hand, one-handed signs that were followed by either another one-handed sign or by a two-handed sign were analyzed. This experiment addressed two main questions: Is H0 during a one-handed sign produced differently when *followed* by another one-handed sign compared to its production when followed by a two-handed sign? And if a difference is found, is the difference affected by rate of signing? The means and standard deviations of the normalized z scores of pinky extension for H0 in first position are given in (6) and are represented graphically in (7).

(6) Pinky Extension Z Score Means (SD) for H0 in First Position

	Position in one-handed sign		
Following environment	**Beginning**	**Middle**	**End**
Following 2-handed sign, fast	.34 (1.11)	-0.39 (.73)	-1.47 (1.15)
Following 2-handed sign, normal	.46 (0.60)	0.19 (0.68)	-0.47 (1.05)
Following 1-handed sign, fast	.25 (.95)	-0.19 (0.67)	-.09 (0.63)
Following 1-handed sign, normal	0.56 (0.56)	0.48 (0.90)	0.47 (0.50)

(7) Pinky Extension of One-Handed Signs in First Position:
Nondominant Hand Mean Z Scores



As can be seen in (7), pinky extension at the beginning of the one-handed sign does not appear to be affected by rate or following sign because little variation was seen across conditions. In the middle and at the end of the sign, the separation of the dark and light symbols indicates that a faster signing rate yields a more index-like handshape. Also at the end of the sign, the separation between the triangles and squares suggests that a following two-handed sign (for which the nondominant hand is specified for an index handshape) causes a more index-like production of H0.

In order to determine whether these different environments yielded significantly different handshapes, a repeated measures ANOVA was conducted. The H0 pinky extension z scores served as the dependent measure, and the independent variables were position within the sign (beginning, middle, or end), following sign (one- or two-handed), and rate (normal or fast).

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Main effects of position, following sign, and rate were found (p<.001). The effects of following sign and rate vary as a function of position within the sign. Three significant interactions were also found: following sign with position, rate with position, and following sign with rate and position, $F(2, 984) = 3.474$, $p<.031$. Bonferroni post hoc tests revealed that the effects attributable to following sign were significant at the end (p<.001) and in the middle of the sign (p<.001). Thus, H0 was more index-like at the end, and to a lesser extent in the middle, of the one-handed sign as it anticipated the index handshape of the following two-handed sign. During a one-handed sign followed by another one-handed sign, the nondominant hand was free to remain in a relaxed posture. The post hoc analysis also revealed that the effects attributable to rate of signing were significant at the end (p<.001) and middle (p<.001) of the sign. Thus a faster rate increased the effects of the handshape of the following sign. In sum, the three-way interaction shows that at the end of the sign, a following two-handed index sign, particularly at a fast signing rate, yielded the most index-like handshapes.

As in the dominant hand experiment, the handshape production at the end of the sign, which is the point closest to the conditioning environment, proved to be susceptible to anticipatory handshape effects. Unlike the dominant hand experiment, however, the anticipatory effects in the nondominant hand are seen as early as the middle of the sign. The gradient effect of following handshape along with the interaction of following handshape with rate suggest that this variation is due to anticipatory coarticulation.

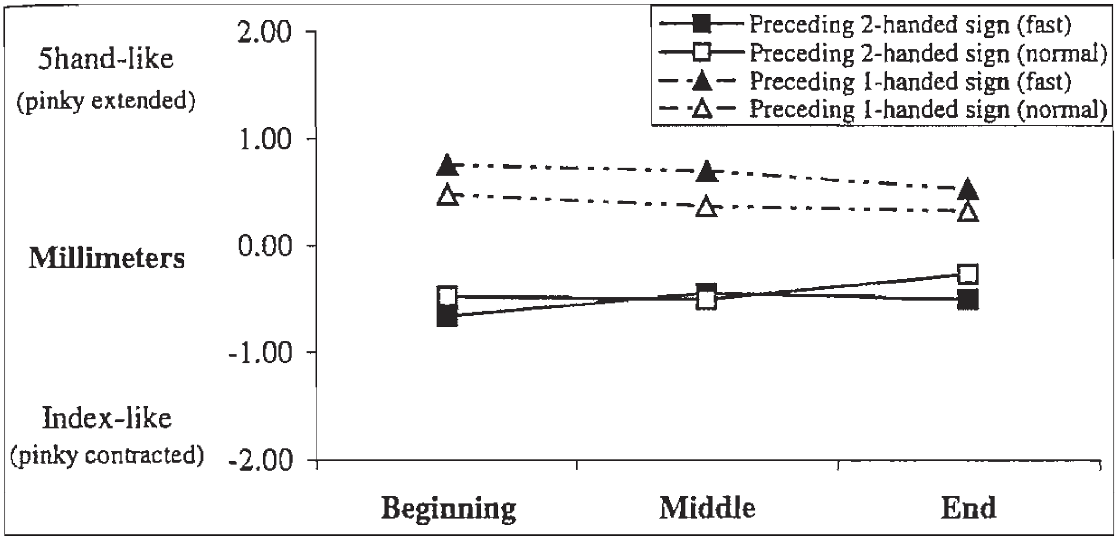
3.2. One-Handed Sign in Second Position

This final analysis answers the question of whether or not perseverative coarticulation occurs in the nondominant hand. For this experiment, the focus was on one-handed signs that were preceded by either another one-handed sign or by a two-handed sign. This experiment also addressed two main questions: Is H0 during a one-handed sign produced differently when *preceded* by another one-handed sign compared to its production when preceded by a two-handed sign? And if a difference is found, is it affected by rate of signing? The means and standard deviations of the z scores in each of the test conditions are given in (8) and are graphically illustrated in (9).

(8) Pinky Extension Z Score Means (SD) for H0 in Second Position

	Position in one-handed sign		
Preceding environment	**Beginning**	**Middle**	**End**
Preceding 2-handed sign, fast	-1.05 (0.80)	-0.87 (0.75)	-0.18 (0.95)
Preceding 2-handed sign, normal	-1.03 (1.01)	-0.42 (0.83)	-0.14 (0.81)
Preceding 1-handed sign, fast	0.44 (0.60)	0.38 (0.59)	0.59 (0.48)
Preceding 1-handed sign, normal	0.89 (0.32)	0.89 (0.32)	0.84 (0.33)

(9) Pinky Extension of One-Handed Signs in Second Position: Nondominant Hand Mean Z Scores



The z scores representing pinky extension at the beginning of the one-handed sign appear to be affected by preceding sign because there is a separation between the triangles and the squares in (13). A similar pattern, though not as extreme, is evident in the middle and at the end of the sign. Clear separations between the light and dark figures occur throughout most of the sign, suggesting that rate may be affecting handshape variation.

In order to determine whether the observed differences were significant, a repeated measures ANOVA was conducted. The nondominant hand z scores taken from signs in second position served as the dependent measure. The independent variables were position within the sign (beginning, middle, or end), preceding sign (one- or two-handed), and rate (normal or fast).

Main effects of position, preceding sign, and rate were found ($p<.001$). Three significant interactions were found: preceding sign with position, $F(2, 1002) = 29.457$, $p<.001$; rate with position, $F(2, 1002) = 5.349$, $p<.005$; and preceding sign with rate, $F(1, 1002) = 7.157$, $p<.008$. Bonferroni post hoc tests at each of the three positions revealed that the effects attributable to preceding sign were significant throughout the one-handed sign ($p<.001$). Thus, H0 produced after a two-handed index sign was more index-like than when produced after another one-handed sign. In these instances, the index handshape of the two-handed sign perseverated throughout the following one-handed sign. Further post hocs showed that the effects attributable to rate were significant at the beginning ($p<.002$) and middle ($p<.001$) of the sign with a faster rate increasing the effects of a preceding one-handed sign.

Unlike the other analyses discussed in this paper, this analysis suggests a categorical effect of preceding handshape because this effect was significant throughout the entire one-handed sign. Based on this finding, the handshape variation observed in

this experiment should be classified as phonological assimilation. Although rate is not expected to condition phonological rules, in this analysis rate did increase the effects of preceding sign. Thus we see some coarticulation, or hypo-articulation, in addition to the categorical handshape assimilation.

4. Conclusion

In sum, the analyses presented in this paper provide quantitative evidence of handshape variation in both the dominant and nondominant hands. This type of research into variation in form in the manual-visual modality demonstrates the usefulness of applying experimental phonetics to issues in sign linguistics. Such methodology gives us a better understanding of variation in form in sign language and allows us to compare the types of patterns found in speech to patterns under investigation in sign. Furthermore, such an approach to sign language research allows us to test hypotheses about phonetic or phonological patterns in both major language modalities so that we can gain a better understanding of phonetics and phonology that is not limited to any specific modality.

In the dominant hand experiments, gradient effects attributable to the handshape of both the following and preceding signs were found. The anticipatory effects were increased at a faster signing rate as would be expected with coarticulatory processes. These findings provide strong evidence of anticipatory coarticulation in the dominant hand. Perseverative coarticulation also occurs, although perseverative variation does not seem to be increased with faster signing. More research is needed to better understand why the perseverative handshape effects appear to be dampened during faster signing. Because of the clearly gradient anticipatory and perseverative patterns found, the synchronic handshape variation observed in the dominant hand is best classified as phonetic coarticulation.

In the nondominant hand, gradient effects of the handshape of the following sign were also found, and these effects were greater at a faster signing rate. As in the dominant hand analyses, the nondominant hand analyses provide strong evidence for anticipatory coarticulation. A different story was found in the analysis of the nondominant hand in second position. Those results showed a categorical effect of preceding sign, which is indicative of phonological assimilation. Additionally, this effect was increased at a faster rate--a characteristic not expected to condition phonological processes. Taken together these findings demonstrate that phonetic and phonological processes can operate simultaneously in sign.

Overall, the synchronic effects of handshape variation discussed in this paper are most likely due to phonetic patterns of coarticulation. The major exception is the categorical effect of preceding handshape found in the nondominant hand. The handshape assimilation observed in the nondominant hand is similar to diachronic patterns of handshape assimilation discussed in the ASL literature on compounds. Handshape assimilation in the nondominant hand has been observed in compounds as the result of historical change (Wilbur 1987, Liddell & Johnson 1986, and Sandler 1993). This type of variation occurs when the relaxed hand that is not used in the production of a given sign anticipates or perseverates the handshape of an adjacent sign. Liddell &

Johnson (1986) describe compounds in which the nondominant hand in the first sign anticipates the nondominant handshape in the following sign. They also note that in compounds made up of a two-handed sign followed by a one-handed sign, the nondominant hand in the second sign may retain the handshape of the preceding sign. Although, we do not see synchronic effects of anticipatory handshape assimilation in the nondominant hand, the motor control factors underlying the perseverative effects observed may have motivated the handshape assimilation observed in compounds today.

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