UNDERSHOOT OF ASL LOCATIONS IN FAST SIGNING[1]

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Abstract

This study extends methodologies previously used to analyze target undershoot in vowels to the analysis of sign location in American Sign Language (ASL). Research has shown that variation in the F2 values of vowels is related to speaking rate such that shorter vowels are less likely to achieve the expected target value for that vowel. Further, this kind of target undershoot is dependent on the phonetic environment in which the vowel occurs. An experiment was conducted to explore whether similar rate-dependent phenomena can be identified in the production of ASL signs articulated at the forehead or in neutral space. Four native signers were asked to produce short utterances at differing rates of production that ranged from normal, relaxed signing to signing that was as fast as possible. Using a multi-camera movement analysis system, kinematic measurements were made of the location of the signer's dominant hand. Rate and context dependence were shown to fit expectations about phonetic undershoot derived from earlier studies of vowel undershoot. This study indicates that undershoot is a cross-modality effect. Similarities between undershoot in the two language modalities are discussed in light of differences between the speech and sign articulators.

1 Introduction

The articulators used for the production of speech sounds and those used for the production of American Sign Language (ASL) signs are radically different in physical form. Speech sounds are made by small movements of the vocal cords, velum, jaw, tongue and lips. Signing involves the coordination of the shoulder, elbow, radio-ulnar joint and wrist to move the arms and hands in space resulting in sign movements that are much larger than movements in speech. The information available for the perception of sign and speech is also radically different; for instance the speech articulators are largely hidden from view, whereas the sign articulators are fully visible. Despite the differences between the two systems, there may be important similarities in the motor control of these systems. Thus, many constraints on language production in one modality may also constrain

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production in the other modality. This study will show that undershoot phenomena are similar across the two modalities and in turn provide support for the validity of extending methodologies for the phonetic analysis of speech to the study of signed languages.

A target is a speaker or signer's acoustic, articulatory or perceptual goal in the production of language. Undershoot occurs when an expected phonetic target is not achieved, often due to constraints imposed by the rate of articulation or the phonetic environment in which the target is situated. Most research on undershoot has focused on vowels in spoken languages. To illustrate the factors that influence the occurrence of undershoot, consider an example from spoken English. The word *wheel* [wil] requires that the tongue body move from the back of the mouth for the labiovelar [w] to the front of the mouth for the front vowel [i] and to the back again for the velarized lateral [l]. While it is relatively difficult to directly examine the movements of the tongue, the acoustic results of those movements are easily observed. The spectrogram in figure 1 demonstrates the changes in the acoustics during the word wheel. The y-axis represents frequency values marked in kHz. Dark bands on the spectrogram represent the resonance frequencies of the complex speech wave; these resonance frequencies are called formants. The second formant (F2) is related to how far backward or forward the tongue is positioned in the mouth. In figure 1, F2 is low reflecting a relatively back position during the [w]. As the tongue moves forward for the front vowel, the value of F2 rises, peaking at around 2000 Hz in normal speech. Finally, the F2 value falls again as the tongue moves back again for the velarized [l].

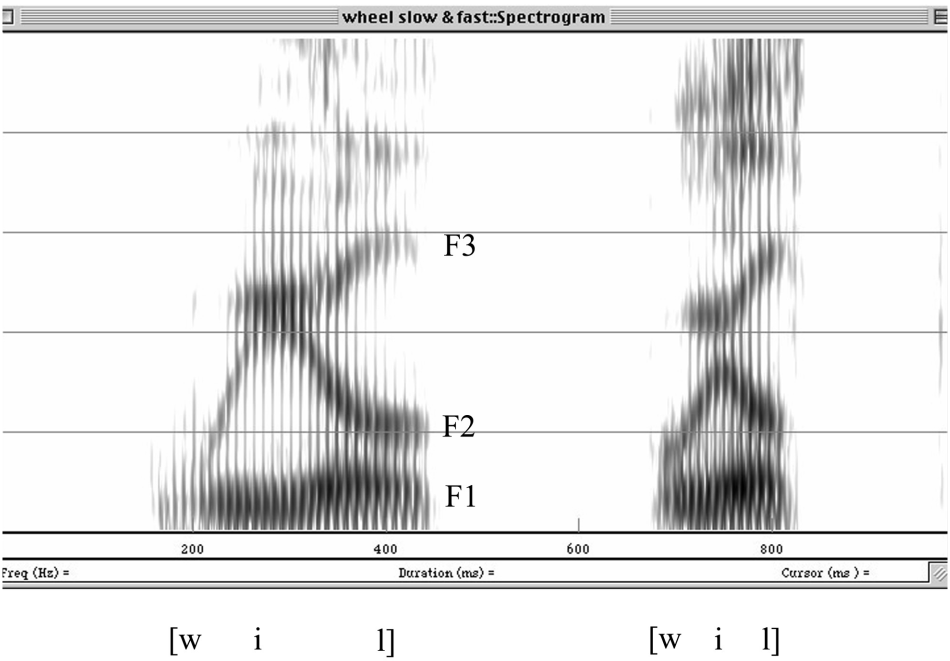

Figure 1: English word wheel *[wil] in normal (left) and fast speech (right).*

Normally, speakers can achieve the pattern of front-back targets in *wheel* with relative ease. However, in faster speech, a speaker may find it difficult to move from one extreme to the other in a short period of time. Although it is possible for speakers to put in extra effort to achieve all targets, often one or more targets is undershot. Figure 1 compares an example of the articulation of wheel in normal speech with an example from fast speech. In the fast speech example, the F2 values for the initial [w] and final [l] are similar to those in the normal speech example. However, the F2 value for the front vowel [i] is lower in the fast speech example, peaking at around 1600 Hz. This spectrogram implies that the tongue body's shift to the front of the mouth was reduced. This reduction is attributable to the extreme difference between the front and back targets and to the limited time available to achieve all three target values in fast speech.

Several studies have shown that the value of a vowel's F2 midpoint is related to its duration and to the F2 values of neighboring consonants (Lindblom 1963, Stevens & House 1963, Kuehn & Moll 1976 and others). Further, an electromyographic (EMG) study of vowels found that muscular effort expended in the articulation of vowels is reduced in fast speech (Gay, Ushijima, Hirose & Cooper 1974). Mauk (2003) showed that undershoot effects can be systematically induced in English stop consonants, resulting in variability in F2 onset values.

If undershoot is a phenomenon based on attributes of motor systems as suggested by the Hyper- and Hypo-Articulation Model of speech production (Lindblom 1990), undershoot effects would be expected for the formational parameters of signed languages. Few studies have examined phonetic variability in the location parameter in sign production. Wilbur and Schick (1987) demonstrated that stressed signs in ASL tend to have locations higher in the signing space relative to unstressed productions. Mauk (1998) found a similar effect when ASL signs are directed to an addressee standing far from the signer. Holzrichter and Meier (2000) showed that ASL-signing parents elevated some signs in child-directed signing. Crasborn (2001) found that shouting in Sign Language of the Netherlands (SLN) also resulted in higher articulations of signs in the signing space, while whispered signs were articulated in a signing space that was relatively compact and low. These examples demonstrate that location variation occurs in signed languages. However, these studies did not directly evaluate signing rate as a cause of this variation. The influence of neighboring handshape on handshape targets has been demonstrated in ASL fingerspelling (Reich 1975, Wilcox 1992) and signing (Cheek 2001). Cheek also showed that the effects increased in fast signing.

The experiment described in this paper applies methodologies associated with the investigation of undershoot to ASL location values. We expected undershoot to result from fast signing of sign sequences that we had constructed so as to juxtapose signs with maximally different locations. For example, in a sequence like SMART CHILDREN SMART shown in figure 2, the dominant hand must move from a relatively high position at the forehead for SMART to a position at the level of the stomach for CHILDREN and back to the forehead again. If undershoot occurs in fast signing, the location value for CHILDREN might rise in signing space as shown in figure 3. Raising CHILDREN results in shortened movement trajectories between each of the signs in the sequence.

Figure 2: ASL sequence SMART CHILDREN SMART.

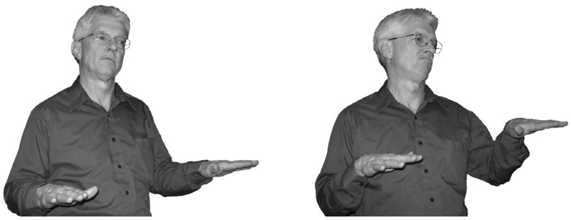

Figure 3: Possible variants in ASL sign CHILDREN *in normal (left) and fast (right) signing.*

1.1 Three-Dimensional Motion Tracking and Sign Language Research

Few researchers have taken advantage of optoelectronic imaging systems for studying signed languages. Data collection using traditional video is limited to only two dimensions for each video image. While two video images can be coordinated to give a visual perspective of all three dimensions, video records are still limited in terms of spatial resolution which prevents precise measurements of movement excursions. An optoelectronic imaging system allows markers on a participant's body to be tracked in three dimensions simultaneously.

Poizner, Newkirk and Bellugi (1983) and Poizner, Klima, Bellugi and Livingston (1986) used a system called Selspot to track aspectual movements in ASL signing. The Selspot system uses a set of infrared light-emitting diodes (LEDs) and two or more infrared sensitive cameras. The LEDs are attached to the signer's body and the cameras record only the movement of those LEDs. The resulting video images are integrated to form a three-dimensional model of the movement of the LEDs. Wilbur (1990) used a similar system called WATSMART to analyze stress in ASL signing. Wilcox (1992) used WATSMART to record and analyze changes in handshapes during fingerspelling. Selspot and WATSMART are active marker systems, since the markers themselves produce the infrared light that the cameras track.

The Vicon system is similar to the Selspot or WATSMART system except that it is a passive marker system, i.e. the infrared-sensitive cameras generate infrared light and the markers are simply small balls covered in silver tape which reflects the infrared light back to the cameras. Vicon has been used in several studies of ASL (Cheek 2001; Cormier 2002; Mauk 1998, 2003). Mauk (1998) compared movement trajectories from normal signing and signing intended for a watcher at a great distance. Cheek (2001) used Vicon to analyze handshape variation. In the current study, we used a Vicon 250 system from Oxford Metrics to capture data on how a sign location is affected by its phonetic environment and by signing rate.

2 Methods

2.1 Subjects

Two male and two female deaf signers of ASL between the ages of 28 and 31 participated in this study. All four were born deaf to deaf parents who used ASL as the primary mode of communication in the family. They were all residents of Austin, Texas at the time of data collection. Participants will be referred to by their initials. MM and RE are female, while AY and TP are male. TP was left-handed, whereas the other three were right-handed.

2.2 Procedures

Prior to data collection, seven 9 mm reflective spheres were taped onto the signer's skin or clothing. Three markers were placed on a signer's shirt at the right and left shoulders and on the sternum; a fourth was placed on the right side of the signer's forehead. The other three markers were placed on the signer's dominant arm at the outside of the elbow, the protrusion of the ulna at the back of the wrist, and the ulnar side of the pinky adjacent to the fingernail. The pinky marker was used in a separate study of undershoot in handshapes that is reported elsewhere (Mauk 2003). For this experiment, the wrist marker was used as an indicator of the location of a sign. The other markers provided a frame of reference for the movement of each sign sequence and assisted in the automation of marker labeling by Vicon. Figure 4 shows the locations of the seven markers with the signer's hands at rest.

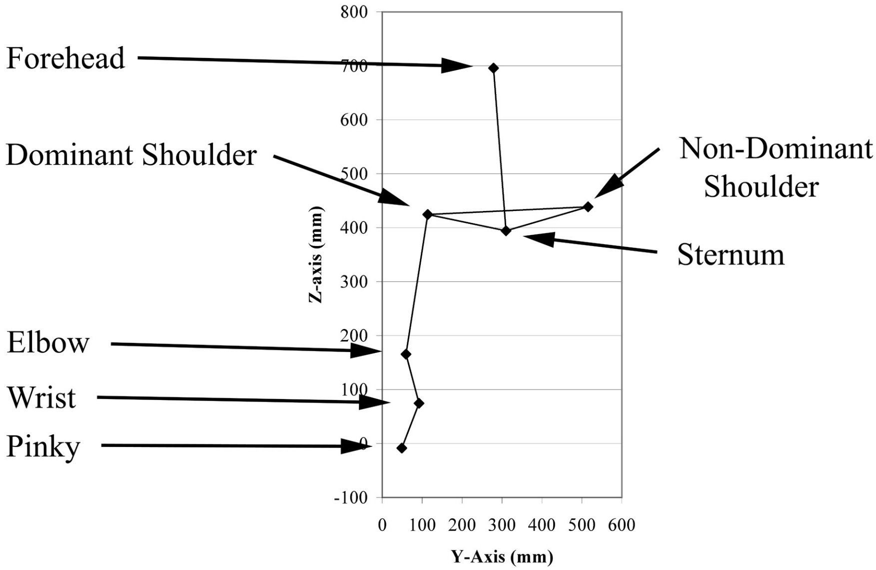

Figure 4: Layout of reflective markers, signer AY.

The Vicon system uses five infrared cameras. Each of the infrared cameras is equipped with an infrared strobe around the lens. Light from these strobes bounces off the reflective markers on the participant's body and is recorded by the cameras at a rate of 60 frames per second (60 Hz). The Vicon data station takes the information from each of the infrared cameras and integrates it, resulting in a model of the movement of the markers in three-dimensional space. The locations of each reflective sphere are measured in millimeters from an origin point established during an initial calibration process. In this experiment, the origin point was located below and behind the seated signer's waist. The x-axis is a horizontal axis running perpendicular to the front of the signer's torso. X-axis values increase as a marker moves forward. The y-axis is also horizontal, but running from right to left parallel to the front of the signer's torso. Y-axis values therefore increase as a marker moves to the signer's left. The z-axis is the vertical axis with increasing values as a marker moves up. Location values for this experiment were determined by vertical (z-axis) displacement from the origin.

2.3 Materials

This experiment focused on two ASL locations. Signs with a forehead location involve contact or close proximity between the signer's dominant hand and the forehead. The signs in this study with forehead locations are shown in Figure 5. The sign FATHER involves repeated contact between the signer's thumb and forehead as the hand repeatedly moves toward and away from the forehead. The sign SMART begins with contact between the forehead and the radial side of the index finger and involves movement of the hand away from the forehead. Location values for forehead signs were taken at a local maximum value (i.e. the highest location value) during the sign.[2]

Figure 5: Forehead located ASL signs: FATHER *and* SMART.

Neutral space is typically defined as the area in front of or to the side of the signer's torso. The two neutral space signs in this experiment are shown in Figure 6. The ASL sign CHILDREN begins with the two hands relatively close to the signer's midline. The hands make two or three up and down "bounces" as they move apart, away from the signer's midline. A one-handed variant of the sign CHILDREN exists involving the same movement as the two-handed variant for the dominant hand, but the non-dominant hand remains at rest. Signers AY and RE preferred the two-handed variant, while TP and MM used the one-handed variant. Only the location of the dominant hand was analyzed in this experiment. The sign LATE begins with the signer's dominant hand on the ipsilateral side of the signer's torso with the palm facing downward. The signer's wrist is then flexed so that the fingertips are pointing down. This wrist movement is repeated and may be accompanied by a downward movement of the arm as a whole. Location values for neutral space signs were taken at a local minimum value (i.e. the lowest location value) during the sign.

Figure 6: Neutral space ASL signs: CHILDREN *and* LATE.

These signs were combined to form four phrases each with three signs; see Table 1.[3] Two phrases had both locations, creating sequences in which a sign with one location was surrounded by signs specified for the other location, e.g. forehead-neutral-forehead. The other two phrases had three signs with the same location specification.

2 For a more detailed discussion of determining measurement points for location values see Mauk (2003).

3 These phrases were not expected to be meaningful expressions in ASL, but all combinations of adjacent signs are valid adjective-noun or noun-adjective sequences that one would expect to see in normal signing.

Sequence of Locations	Sign Phrases
Forehead-Neutral-Forehead	SMART CHILDREN SMART
Neutral-Forehead-Neutral	LATE FATHER LATE
Forehead-Forehead-Forehead	SMART FATHER SMART
Neutral-Neutral-Neutral	LATE CHILDREN LATE

Table 1: Sign phrases used as stimuli in this study.

Sign phrases containing both locations were expected to exhibit undershoot effects. For example, in the forehead-neutral-forehead sequence, the position of the neutral space sign could move up toward the forehead location as signing rate increases, or the forehead located signs could move downward toward the neutral space sign. Sign phrases with only one specified location were not expected to display regular variation in that location.

At the beginning of each phrase, the signer's hands moved upward from a position of rest, usually from the signer's lap. Likewise, at the end of each phrase, the signer's hands returned to rest. The low position of the hands at the beginning and end of each phrase might have caused the articulation of the first and third signs in these phrases to be lower than would normally be expected if those signs were in a medial position within a phrase. Therefore, undershoot effects are discussed here primarily with regard to the second sign in each phrase.

Participants were asked to sign these phrases in four manners: a) normal, relaxed signing, b) signing faster than normal but not so fast that the participant or experimenter felt the signing lost intelligibility, c) signing that was even faster but without any special instructions about intelligibility, and d) signing that was "as fast as possible". Signers were allowed to determine their own signing rate using these instructions as general guidelines. These conditions resulted in a range of signing rates from normal to very fast. It was not expected that all signers would necessarily interpret these instructions in precisely the same manner.

Sign phrases were presented to the participants typed on slips of paper measuring 8.5" x 2.75". The investigator sat at a small table and held the slips of paper up for the signer to read as he or she articulated the sequence. The slips were laid face down as the participant finished each phrase. The phrases were randomized within each block. A total of 10 blocks were elicited for each rate condition. In total, 10 renditions were collected of each of the 4 phrases in each of the 4 speaking conditions. A total of 160 phrases were collected from each participant for this experiment.

3 Results

As expected, location values were found to vary across the rate conditions and across phonetic contexts. A separate three-way ANOVA was run on the data from each participant. The three independent variables were signing rate (normal, fast clear, fast unclear, or fastest), phonetic environment (neutral space or forehead signs) and target location of the medial sign (neutral space or forehead). The dependent variable was the vertical location of the wrist marker in millimeters (mm). Separate ANOVAs were conducted for each subject because substantive individual differences between the signers were found. Table

1 below shows the significant effects for each signer. The main effects of phonetic environment and target were significant for all four participants and signing rate was significant for three of the four. Crucially, for each signer one or more significant interactions were found. A series of Tukey's HSD post hoc comparisons was conducted in order to explore the sources of the deepest level of interaction for each signer. In the sections to follow, the patterns of variation for each signer will be discussed

	Signer AY	Signer MM	Signer RE	Signer TP
Independent Variables	F (df)	F (df)	F (df)	F (df)
Signing Rate	20.76 (3, 143)**	1.52 (3, 143)	8.52 (3, 144)**	36.19 (3, 142)**
Phonetic Environment	37.77 (1, 143)**	122.89 (1, 143)**	16.54 (1, 144)**	163.74 (1, 142)**
Target	11,146.23 (1, 143)**	1,436.48 (1, 143)**	8,580.94 (1, 144)**	456.88 (1, 142)**
Rate x Environment	14.75 (3, 143)**	15.28 (3, 143)**	1.24 (3, 144)	3.89 (3, 142)*
Rate x Target	29.33 (3, 143)**	29.81 (3, 143)**	14.22 (3, 144)**	4.75 (3, 142)**
Environment x Target	84.84 (1, 143)**	16.30 (1, 143)**	2.10 (1, 144)	56.78 (1, 142)**
Rate x Environment x Target	8.88 (3, 143)**	2.15 (3, 143)	0.04 (3, 144)	5.95 (3, 142)**

* $p < 0.05$
** $p < 0.01$

Table 2: Results of three-way ANOVAs on location measurements from each participant.[4]

3.1 Signer AY

The analysis of the results from signer AY revealed a significant three-way Rate X Environment X Target interaction. Figure 7 shows mean location values and standard deviations for the medial sign in each phrase and in each rate condition produced by signer AY.

4 Degrees of freedom differ between subjects because some trials were thrown out due to occlusion of the wrist marker at crucial points in the trajectory. 1 trial each was discarded for signers AY and MM and 2 trials for TP.

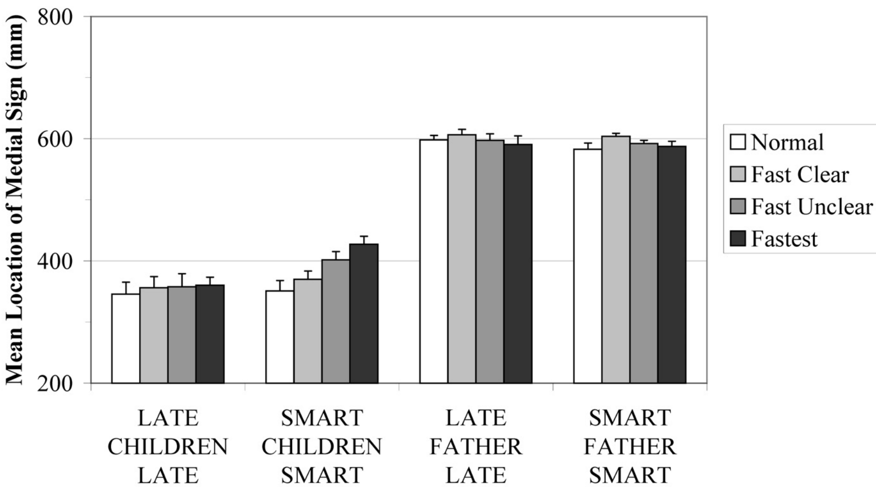

Figure 7: Mean location values for medial signs by rate and environment for signer AY.

Inspection of the Tukey's HSD post hoc comparisons revealed that the neutral space sign CHILDREN showed rate-dependent variation when preceded and followed by the forehead sign SMART. In each rate condition, the dominant hand[5] moved from a fairly high location for the forehead-located sign SMART, to a relatively low location for the neutral space sign CHILDREN and then back to the forehead location. In the normal signing condition, the hands moved approximately 180 mm downward from forehead to neutral space. In the fastest condition, that excursion was reduced to approximately 100 mm. The shortened excursion resulted from an elevation of the location value for the neutral space sign. In contrast, the mean locations for the sign SMART were relatively stable with little variation across the elicitation conditions. Tukey's HSD post hoc tests reveal that, for signer AY, the normal and fast clear signing rates were significantly different from the fast unclear and fastest signing rates ($p < 0.01$) and the fast unclear and fastest signing rates were also significantly different ($p < 0.01$).

The only other significant result revealed by post hoc analyses of the data from signer AY was in the forehead-forehead-forehead sentence types. For AY, the normal and fast clear rate conditions were found to be significantly different ($p < 0.05$) such that the target sign FATHER was elevated in the Fast Clear signing rate condition. This result resists interpretation, in that no reliable rise in the location of FATHER was found in the Fast Unclear or Fastest signing rate conditions.

5 Only the location of the dominant hand in the sign CHILDREN was analyzed. Raising may have also occurred for the non-dominant hand, but data on the location of the non-dominant hand were not collected.