Production fluency in spoken language users acquiring a sign language as an L2 in adulthood

by

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In loving memory of my father Dr. William N. Hilger, Jr.
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Abstract

A study was conducted to examine production variability in American Sign Language (ASL) in order to gain insight into the development of manual fluency. Production variability was characterized through the spatiotemporal index (STI), which represents production stability in whole-utterances and is a function of variability in effector displacement waveforms (Smith et al., 1995). Motion capture cameras were used to acquire hand and limb displacement data across a set of eight target signs embedded in carrier phrases. The STI values of Deaf signers and hearing learners at three different ASL experience levels were compared to determine whether production stability varied as a function of time spent acquiring ASL, as it is for spoken English (Kleinow and Smith, 2000). We hypothesized that higher production variability as indexed by higher STI values would be evident for beginning ASL learners, with variability decreasing as ASL language experience increased. As predicted, Deaf signers showed significantly lower STI values than the hearing learners, suggesting that stability of production is indeed characteristic of increased ASL use. A linear trend across experience levels of hearing learners was not statistically significant, indicating that improvement in production fluency across relatively short time scales was not observed. This novel approach to characterizing fluency in ASL utterances has relevance for assessing L2 acquisition of sign languages and possibly for the characterization of sign production disorders.
Introduction

Sign languages are the natural languages of Deaf communities and possess phonological systems, morphological systems and syntactic rules, operating within complex grammatical systems (Sandler and Lillo-Martin, 2006). The acquisition of sign languages by Deaf children with Deaf parents follows the general milestones that characterize acquisition of spoken language for hearing children (Newport & Meier, 1985; Petitto and Marentette, 1991). Sign languages also exhibit sociolinguistic variation (Lucas, 2001) and undergo historical change (Frishberg, 1975). They differ from spoken languages primarily in that they are expressed in the visual-gestural modality, rather than the oral-aural modality.

Second language acquisition of sign languages by individuals who have a spoken language as an L1 is of particular interest. This is because it not only requires learning lexical items and a grammatical system, but the language must be produced with an entirely new set of articulators. Acquiring a new articulatory system in an L2, involving the use of the hands, arms, and facial expression, presents a novel challenge for learners who have a spoken language as L1. Importantly, these effectors also present a research advantage in that the articulators are all visible, in contrast to speech articulators such as the tongue that are hidden from view and challenging to track experimentally. The focus here is on production fluency in hearing L2 learners of American Sign Language (ASL), and in particular their ability to consistently reproduce utterances. We propose that one metric of high production fluency is the ability to reproduce lexical targets from a sign language with low spatiotemporal variability in the movement of the dominant articulators. In this view, variability is used as an index of the robustness of the motor representations acquired by the hearing L2 learner.
Whilst there have been several studies of sign language acquisition as an L1 in deaf individuals (Newport & Meier, 1985; McIntire, 1977; Meier & Newport, 1990), comparatively little is known about L2 sign language acquisition in hearing individuals. Mirus et al. (2001) looked at motor movements in adult hearing learners acquiring ASL as a second language. The study was motivated by prior research showing that Deaf children learning sign language often proximalized movements that required more distal articulation, or used articulators closer to the torso when articulators further away are required (Meier, 1998). Hearing adults with little or no prior sign language knowledge were asked to imitate a set of signs from either ASL or German Sign Language (DGS - Deutsche Gebärdensprache). Additionally, native or near-native Deaf signers of ASL were asked to imitate a set of signs from DGS to determine whether familiarity with the manual modality played a role. Mirus et al. reported that proximalization of signs was frequently observed in the adult hearing learners but not in the Deaf ASL signers imitating signs from DGS, suggesting that the native signers have an acquired set of motor skills that could be transferred to articulation of other sign languages. One implication of this finding for second language acquisition of a sign language for adult learners without prior sign language experience is that it may be more complex than for spoken L2 acquisition due to a completely new set of motor skills that must be acquired and molded to linguistic constraints.

*Characterizing Production Fluency*

The study reported here is an initial attempt to explore this measure of production fluency in hearing adults learning American Sign Language (ASL) as an L2 on a university campus in the United States. Kinematic analysis of sign language data acquired using motion capture technology allows for the examination of specific movements in order to gain understanding of their phonetic, phonological and syntactic properties. Several studies have used this approach to
investigate aspects of sign language processing: covert articulatory rehearsal (Emmorey et al., 2009), coarticulation and phonetics in fingerspelling (Jerde et al., 2003, Tyrone et al., 2010, Wilcox, 1992), linguistic aspects of sign languages such as phonetics, phonology, and semantics (Cheek, 2001, Cormier, 2002, Mauk, 1999, 2003, Poizner et al., 1983, 1986), physical stress in interpreting (Qin et al., 2008), linguistic stress in signing (Wilbur, 1990), and comparisons between gesture and signing (Wilbur & Malaia, 2008).

Originally employed by speech scientists to better capture the complex kinematic variation of speech articulators such as the lower lip and jaw (Smith et al., 1995), kinematic variability analysis also has the potential to be useful when applied to production stability in sign languages. This study uses the spatiotemporal index (STI) -- a measurement, based upon kinematic data, which has been used to examine production stability in stuttering (Smith & Kleinow, 2000). The STI measures kinematic variability in utterances over repeated performances (Smith et al., 1995). This measurement draws on the theory from Schmidt et al., (1988), in which underlying movement patterns were identified in the timing sequencing of complex arm movements, reporting invariance in the overall sequences and suggesting a common core structure. Originally, the STI was employed to examine underlying production components in speech, looking at the preprogramming of speech movements by observing the stability of repeated productions of an utterance by a normal adult speaker in the absence of perturbation (Smith et al., 1995). The STI has also been used to examine movement stability of oral articulators in speech with rate variation and grammatical variation (Smith & Kleinow, 2000; Kleinow & Smith, 2000). Fluent speakers show speech movements that were highly automatic and stable, whereas a person who stutters exhibited less stability / higher STI (Kleinow & Smith, 2000).
Chakraborty et al. (2008) used the STI to study second language acquisition in Bengali learners of English. They reported no significant differences between the STI values for the speakers’ L2 and L1, suggesting that production stability (as indexed by the STI) may not be a fluency characteristic in adult second language acquisition of spoken languages. This suggests that there is significant transfer of articulatory control between two languages that share a common set of articulators. Due to the need to learn new motor plans to control the effectors required to produce a sign language, we hypothesized that L2 sign language acquisition would result in higher levels of production variability as indexed by the STI. We also predicted that with increasing exposure to and practice in producing the language, movement instability should decrease until it approximates the levels observed in native or near-native Deaf L1 signers.

In order to do this, we calculated STI values for eight ASL sign productions embedded within carrier phrases produced by hearing L2 learners of ASL and proficient Deaf signers for whom ASL was an L1. We predicted that the Deaf proficient signers would show significantly smaller STI values (indicating less variability and stronger stability) than the hearing learners, reflecting the need to acquire a complex set of new motor skills in this novice signing population. We also predicted that STI values would be lower in hearing learners with more sign language experience, reflecting increasing automaticity of motor planning as a result of practice in producing ASL utterances.

**Methods**

**Participants**

Participants were recruited from each of three levels of the ASL curriculum at the University of Illinois at Urbana-Champaign, and from the Deaf community in Champaign-
Urbana, Illinois. The ASL curriculum consists of ASL I (beginning level), ASL II (intermediate level), and ASL III (advanced level). Each level consists of 4 hours of classroom contact time per week with a Deaf instructor across a 16-week semester, in addition to weekly assignments. At the time of the study, students in ASL I had 8-14 weeks of classroom experience, students in ASL II had 22-28 weeks, and students in ASL III had 36-42 weeks. Four students were recruited from each level, in addition to four native, or near native, Deaf signers from the local community (Deaf, proficient signers). Thirteen of the participants were female and three were male, ranging from 19 to 60 years of age.

**Apparatus**

Kinematic data was collected at 100 frames per second using 4 Hawk motion capture cameras (Motional Analysis Corporation, Santa Rosa, CA). The cameras emit and sample infrared light that is reflected from passive reflective markers placed on the participant. For each participant, markers were placed on the right shoulder, upper arm, upper elbow, lower elbow, wrist, and hand. A single marker to follow head movement was also attached to a pair of plastic glasses worn by the participant. Markers were calibrated for motion of less than 0.5mm using the procedures recommended by the Motion Capture calibration protocol. Real-time video at 60 frames per second, time-aligned with the motion capture system, was also acquired.

**Materials and Procedure**

Participants were seated 4 feet from a computer screen. Instructions were presented with a captioned video in ASL to Deaf L1 signers and verbal instructions in spoken English to hearing L2 learners. Each trial consisted of a phrase appearing on the computer screen in English glosses of ASL signs, with a video demonstrating only the target sign. This allowed for the experiment to
be accessible to the beginning signers while avoiding passive imitation. After each phrase, a slide showing the word ‘STOP’ appeared.

The stimuli consisted of eight target signs embedded in two carrier phrases (adapted from Emmorey et al., 2009). In order to maintain grammatical consistency, the target signs GROW-UP, STRAIGHT, DANCE, WIFE, and FURNITURE were embedded in the phrase THINK ________ YESTERDAY, while the signs PREACH, PUT, and LOOK were embedded in KNOW ________ YESTERDAY (see Figure 1). The participants were instructed to sign the phrase shown on the screen in a natural, conversational manner, and to begin and end with their hand placed on their right thigh.

For each sign, the subjects were seated with the right side of their body facing the cameras so that forward-backward motion occurred in the Y-dimension, side-to-side motion in the X-dimension, and up-down motion in the Z-dimension. The stimuli were ordered randomly, with ten trials for each of the eight target signs (eighty trials per participant).

Movement Analysis

Visual inspection of the target signs suggested that the principal direction of motion for most markers was in the Y-dimension (horizontal motions away from and returning to the torso). The right hand marker was chosen for all analyses as it was most clearly displaced across a large range of motion on each trial for each sign.

The target signs were extracted from the carrier phrase of the right-hand marker record using a custom Matlab script. The start and end points of the target sign were defined as the first and last valleys in the trace where the hand moves toward the body for the signs in the carrier phrase. This allowed for consistency across all signs for all subjects.

Dependent Variables
The STI was determined for the hand marker in the Y-dimension for each participant in order to quantify and compare movement variability across the ten trials of each sign. The STI is calculated by normalizing the displacement into Z-score and normalizing the temporal record of each movement trace onto a common time frame (following procedures established by Smith et al., 1995). After temporal normalization of all trials to 1000 points, the standard deviation across the 10 displacement normalized trials was sampled at 2% intervals in the amplitude domain. The standard deviation (SD) indicates the temporal and spatial variability at a single point. By summing the SD values for each sign, an index of variability was derived that samples variability across all trials for a given sign. For each participant, an STI value was calculated for each sign. Lower STI scores thus indicate more consistent or less variable movements. Averages of the STI values were then compared between the groups. In order to assess whether increased variability was driven by increased duration of utterance, the production duration of each sign in real-time based on the marker points was also recorded for each trial.

Statistical Analysis

Linear mixed models were used to analyze the data using the MIXED procedure in SPSS (Windows version 21, IBM). Participant group was treated as a fixed variable, and sign was analyzed as a random variable. The criterion for significance (alpha) was set at .05, and a priori contrasts were performed to test the experimental hypotheses.

Results

The STI values were computed for each participant for each of eight signs, based upon 10 independent productions of each sign (a total of 80 tokens). In addition, the time it took participants to produce each token was recorded.
A linear mixed model analysis was performed with ‘group’ as a fixed variable (Deaf proficient signer, ASL III, ASL II, ASL I), ‘sign’ as a random variable (GROW-UP, STRAIGHT, WIFE, DANCE, FURNITURE, LOOK, PREACH, and PUT), and sign ‘production duration’ as a covariate. The dependent variable was the STI value for each sign for each participant. This analysis revealed a statistically significant effect of group ($F(3, 116) = 6.91, p < .001$), with production duration not a significant covariate ($F(1, 122) = 2.16, p = .144$).

Next, we examined specifically whether the hearing learners would differ from the Deaf proficient signers. This was analyzed using a contrast comparing the performance across the hearing learner groups with the performance of the Deaf proficient signers. Taking production duration into account as a covariant, this showed a significant difference between the STI values of the hearing and Deaf groups: $t(116) = -4.27, p < .001$ (see Figure 2). The 95% confidence interval for the STI difference between hearing learners and the Deaf Proficient signers was (-2.75, -7.51).

Finally, we analyzed whether there was a significant linear trend in the STI values going from ASL I learners through to ASL III learners. A linear mixed model, with Deaf signers excluded, was not statistically significant ($F(2, 85) = 1.04, p = .356$). Production duration was not a statistically significant covariant: $F(1, 92) = 3.91, p = .051$.

**Discussion**

The kinematic variability of sign production in hearing learners of ASL was assessed using the spatiotemporal index (STI) – a measure of production variability across repeated tokens of an utterance. Hearing learners at three proficiency levels were assessed, and compared with Deaf proficient signers who acquired ASL as an L1 in infancy or early childhood. For
hearing speakers acquiring a sign language for the first time, we predicted that production variability would be greater than for Deaf proficient signers because motor plans for speech are more challenging to co-opt for motoric production of sign (c.f. spoken languages, Chakraborty et al., 2008). As predicted, the STI values for hearing learners were larger than for Deaf proficient signers, reflecting greater variability in production across performance tokens in hearing learners. There was a small reduction in STI values across proficiency levels, suggesting that increasing experience of producing a sign language results in more consistent articulation of the language. However, this trend was not statistically significant; the most proficient hearing learners were still less consistent than the Deaf proficient signers. However the most proficient learners in this study had only been using ASL for 36-42 weeks, compared to Deaf proficient signers who had been using ASL as a primary language for 19-60 years.

We interpret these results as reflecting refinement of the motor plans needed to produce ASL signs, with increasing experience leading to more stable representations of those motor plans and consequently less production variability. However, this does not necessarily mean that variability is entirely synonymous with fluency in the language itself. Post hoc inspection of some productions by hearing learners suggested that while they were consistent in how they articulated signs, their articulation patterns often diverged from that of Deaf L1 signers. For example, the sign GROW-UP is produced by placing a handshape palm-downwards in front of the signer, and then moving that handshape upwards twice to successively higher locations (see Figure 3). When the Deaf signers produced the sign, movement in the y-dimension decreased with each successive movement (Figure 4A), whereas the hearing learners produced successively larger movements (Figure 4B-D).
Whereas the data are informative and compelling, there are various limitations of this study. This study utilized a cross-sectional design that may have over-estimated the increases in production stability for hearing L2 learners as a whole. At each level of the curriculum it is possible that some dysfluent L2 signers who are struggling with the language end up dropping out of the ASL course sequence. While dropout rates are low, longitudinal studies with larger numbers of learners are needed in order to accurately generalize to the population of hearing L2 learners. This study also represents analysis of only one dimension. While the STI measure appears sensitive enough to see an effect of ASL experience in L2 learners on production variability using just the articulatory dimension of path movement, the data clearly may not reflect the total variability in production in hearing learners. In addition, we have focused only upon the movement of a single limb articulator whereas a more global perspective on fluency in ASL would follow the coordinated movement of the hands, arms and body, which are further synchronized with head movements and facial gestures. Finally, these data come from the production of individual signs embedded within carrier phrases. Analysis of more complex utterances that require additional morphological and syntactic knowledge may reveal larger patterns of variability and more insight into how increasing grammatical competence is associated with production fluency.

Studies that address these limitations will allow us to better characterize production fluency in both hearing L2 learners and L1 Deaf and hearing signers. Such knowledge has implications for teaching and assessment in both second language curricula and interpreter preparation programs, as well as for the diagnosis of communication disorders in Deaf children and adults. The sensitivity of the spatiotemporal index reported here suggests that it may be a
useful research tool for sign language learning and possibly assessment as it has been used for spoken language research.
References


Kleinow, J., and Smith, A. (2000). Influences of length and syntactic complexity on the speech


Figures and Figure Legends

**Carrier Phrase**

![Carrier Phrase illustrations](image)

**Target Signs**

![Target Signs illustrations](image)

Figure 1: Illustrations of the eight target signs and two carrier phrases (adapted from Emmorey et al., 2009).
Figure 2: STI values varied as a function of proficiency level; higher values indicate greater variability in production. Solid circles indicate group means, and open circles indicate STI values for individual participants averaged across signs.
Figure 3: The ASL sign translated as GROW-UP is articulated with a bent $\mathcal{B}$ handshape. The hand is held palm downwards in front of the body and moves upwards.
Figure 4. Normalized hand motion in the Y dimension with displacement plotted against time. Each light-colored line shows one of the ten trials for the sign GROW-UP, and the bolded line shows the average movement trace pattern.