Handshape complexity as a precursor to phonology: Variation, Emergence, and Acquisition

Diane Brentari (Department of Linguistics, University of Chicago)
Marie Coppola (Departments of Linguistics & Psychology, University of Connecticut)
Pyeong Whan Cho (Department of Cognitive Science, Johns Hopkins University)
Ann Senghas (Department of Psychology, Barnard College, Columbia University)

Keywords: phonology, sign language, gesture, emerging language, language acquisition, handshape, complexity, language variation

Running head:

Handshape complexity as a precursor to phonology

Abstract

In this paper two dimensions of *handshape complexity* are analyzed as potential building blocks of phonological contrast—*joint complexity* and *finger group complexity.* We ask whether sign language patterns are elaborations of those seen in the gestures produced by hearing people without speech (pantomime) or a more radical re-organization of them. Data from adults and children are analyzed to address issues of cross-linguistic variation, emergence, and acquisition. Study 1 addresses these issues in adult signers and gesturers from the United States, Italy, China, and Nicaragua. Study 2 addresses these issues in child and adult groups (signers and gesturers) from the United States, Italy, and Nicaragua. We argue that handshape undergoes a fairly radical reorganization, including loss and reorganization of iconicity and feature redistribution, as phonologization takes place in both of these dimensions. Moreover, while the patterns investigated here are not evidence of duality of patterning, we conclude that they are indeed phonological, and that they appear earlier than related morphosyntactic patterns that use the same types of handshape.

1. Introduction

Starting with the work of Stokoe (1960) over fifty years ago, linguists have shown phonological structure in sign languages to be similar in many ways to spoken language phonology. In sign language phonology, the basic manual parameters are the handshapes, locations, and movements of signs. With respect to the features of these parameters, sign languages have minimal pairs, phonological production rules, and hierarchical feature structure autonomous from other components of the grammar, like that of their spoken language counterparts (for recent overviews see Brentari 2011a,b, 2012; and Sandler 2011, 2012). Studies of acquisition reveal that the acquisition of phonological structure proceeds along a time course similar to spoken languages with comparable complexity in morphology and morphophonology (Boyes Braem 1981; Marentette & Mayberry 2000; Morgan, Barrett-Jones & Stoneham 2007; Volterra 1987; Tang, Lam, Sze, Lau & Lee 2008; Meier, Mauk, Cheek & Moreland 2008; Chen-Pichler 2012).

In this paper we examine how one parameter in a sign language—handshape—might vary crosslinguistically: how it emerges in historical time, and how it might be guided, in part, by mechanisms of language acquisition. As a language is passed from one generation to the next, child learners can have an influence on its structure, ultimately acquiring a language that differs from the one modeled by the previous generation (Sankoff & Laberge 1973). We are fortunate to have the opportunity to observe such developments in a very young language, Nicaraguan Sign Language (NSL), which has emerged over the past four decades. By comparing the signs of Nicaraguan adults and children with the signs of more well established sign languages, and by comparing these signs, in turn, with the gestures produced by hearing members of the local spoken language communities, we can capture the nature of the earliest elements of sign language phonology. We cannot observe how the emergence and acquisition of phonology relate to one another in spoken languages, because the relevant development took place millennia in the past, but we can do so in the manual modality by observing presently emerging sign languages such as NSL. We would expect that in the earliest years of the emergence of a new language, the impact of the acquisition process would be most evident, as aspects of the grammar first take on a systematic structure (Senghas 1995; Senghas & Coppola 2001).

Handshape is one of the sub-lexical phonological units of sign languages and can be thought of as a natural class, the way that obstruents (stops and fricatives) form a natural class in spoken languages. Consider that obstruents have a particular time course in first-language acquisition. They appear as single consonants before they appear in clusters, in word-initial position before word-final position, and stops are mastered before fricatives (Vihman, 1996). Moreover, these sounds are mastered later where they interact with morphology than where they are a part of simple stems (see MacWhinney, 1978, for English, and Ravid & Schiff, 2009, for Hebrew). This kind of interaction of phonology and morphology, with respect to the natural class of handshapes, is the focus of this article. The interaction is examined in the contexts of sign language acquisition and emergence.

We start from the assumption that sign language has both gestural and linguistic elements, and by comparing signed and gestured responses we can distinguish the parts of the signed system that are due to *linguistic* rather than to the *gestural* properties of responses. Patterns that are shared by signers and gesturers are considered to be gestural—i.e., not the forms alone, but rather the distribution of those forms in the system. In the following two studies the complexity of two types of handshapes that are ubiquitous and meaningful in both sign and gesture are examined: *Object handshapes*, those in which the hand represents properties of objects, such as size, shape and class, and in so doing use "hand-as-object" iconicity, and

Handling handshapes, those in which the hand represents how objects are manually manipulated, and which use "hand-as-hand" iconicity (see Figure 1 for examples).

Handling handshapes Object handshapes

Figure 1: Examples of Handling and Object handshapes.

Handshape was chosen as a focus of our studies because handshape has been shown to exhibit notable differences between gesture and sign, particularly in adults, and much more so than movement and location, the two other manual sign language parameters (Goldin-Meadow, McNeill & Singleton 1996; Schembri, Jones & Burnham 2005).

The first study replicates and expands on previous work on this topic with adults from Italy and the United States (Brentari, Coppola, Mazzoni & Goldin-Meadow 2012). We compare the handshape complexity of deaf adult signers to that of hearing adults gesturing without speaking, across four countries: Italy, the United States, Nicaragua and China. Complementing this prior work, we analyze both finger complexity and also joint complexity, a second dimension of handshape not previously considered. Three of the four sign languages are well established—American Sign Language (ASL), Italian Sign Language (LIS) and Chinese Sign Language (CSL)—dating back at least 100 years (Fischer & Gong 2010; Quer, Mazzoni & Sapountzaki 2010; Brentari 2010). The fourth sign language is the newly emergent Nicaraguan Sign Language (NSL); thus we can examine how historically related (LIS and ASL) and unrelated (CSL) sign languages behave with respect to these two types of handshapes, and how a more recently developed sign language (NSL) fits in.

In addition to the sign language analyses, we also will analyze the patterns produced by adult gesturers from these four countries to understand potential differences in gesture systems in these four very different cultures; these comparisons will allow us to determine if there are differences across country that apply to both sign language and gesture. In the earlier work (Brentari, et al., 2012) sign language and gesture groups demonstrated different patterns from one another along the first of the two dimensions studied here. In both Italy and the US, signers showed higher selected finger complexity in Object handshapes and lower selected finger complexity in Handling handshapes. Gesturers showed the reverse pattern: higher selected finger complexity in Handling handshapes and lower selected finger complexity in Object handshapes. Some differences across country were also found, but not further explored in the earlier work.

In the second study presented here, we examine the acquisition of finger group and joint complexity in the handshapes produced by deaf child signers and hearing child gesturers in three of the four countries from Study 1—Italy, the US, and Nicaragua—to determine if there are differences between children and adults.

These studies strengthen and extend previous work by analyzing two dimensions of handshapes—joint complexity and finger group complexity—to see how the two types of handshape properties interact with one another: i) in gesture vs. sign languages, ii) across different sign languages that are unrelated and have different historical depth, iii) across different gesture systems from the surrounding spoken language communities, iv) in acquisition; and (v) across countries. The following three sections present the background for handshape in morphosyntax and morphophonology relevant for the current studies.

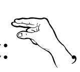
1.1. Properties of Handling and Object handshapes: Morphosyntax

Both handshape types under investigation are iconic. That is, there is a non-arbitrary relationship between the form of the signs and their meaning. In Brentari et al. 2012 the term "hand-as-object" is used to describe the iconicity in Object handshapes, since the shape of the hand assumes visual properties of the object, such as straight, wide, or round. The term "hand-as-hand" is used to describe the iconicity in Handling handshapes, since the hand represents the hand holding or manipulating an object. These types of meaning are available to signers and gesturers alike, by means of the iconicity. In spoken languages, sound symbolism is meaningful and often acoustically onomatopoetic, but rarely morphological (Hinton, Nichols & Ohala 1994).

In sign languages, iconic elements of handshape exhibit morphological and syntactic properties as well (morphology: Supalla 1982; Engberg-Pedersen 1993; syntax: Kegl 1990; Janis 1992; Benedicto & Brentari 2004). Handling and Object handshapes participate as productive morphological affixes of the classifier predicate systems of many sign languages to the extent that they are stable across related contexts. These same handshapes are used in other contexts where they have iconic meaning, including lexical items such as monomorphemic nouns and verbs, but they behave as morphological elements only in classifier predicates (Brentari & Padden 2001). In classifier predicates Handling and Object handshapes display syntactic oppositions as well; Handling handshapes are associated with clauses containing an agent, while Object handshapes are associated with non-agentive, particularly unaccusative clauses (Benedicto & Brentari 2004)—e.g., [someone] moves a book (agentive) vs. a book moves (non-agentive).

There are several types of classifiers in sign languages; only three are relevant to our current study: *Handling*, in which the handshape represents the hand that manipulates the object (Supalla 1982); and two types of object classifiers: *whole entity*, in which the handshape represents the object as a whole or class of object rather than its parts (Engberg-Pedersen 1993), and *size-and-shape,* in which the handshape represents a subset of the properties of an object (Supalla 1982). Both whole entity and size-and-shape constructions are referred to as *object* classifiers throughout this paper. Object classifiers affix to sign movements that indicate either a specific location or a movement of an object. Examples are given in (1)-(3) below:

(1) *Handling* classifiers

a. handle a flat object: , all fingers bent only at knuckle joint
b. handle a small object: , index bent at knuckle joint; pads of thumb and index touch

(2) *Whole entity classifiers*

a. vehicle: , thumb, index, and middle fingers extended
b. airplane: , thumb, index, and pinky fingers extended

(3) *Size and Shape Specifiers*

a. long-thin-object: , index finger extended

b. small object: , index finger curved

1.2. Properties of Handling and Object Handshapes: Phonology

The hand is not treated as an undifferentiated whole in sign language phonology; handshape has several sub-components. The representation of handshape includes a branch in the feature tree representing the "active", "foregrounded", or "selected" fingers in a given handshape (see Figure 2) vs. those that are *nonselected*. *Selected fingers* are those that move or contact the body during the articulation of a sign. Modifications of selected fingers create minimal pairs in ASL and are important for the application of phonological rules in several sign languages, including ASL, Israeli Sign Language (ISL), and Nederlandse Gebarentaal (Sign Language of the Netherlands, or NGT) (Klima & Bellugi, 1979; van der Hulst 1995; Meir & Sandler, 2007). Moreover, the features of *selected fingers* form natural classes of handshapes, such as the *index finger group* , which contains , , , , and —i.e., all handshapes with only the index finger selected make up a natural class of handshapes (similar to the sub-groupings of obstruents in English as they combine with the features of place of articulation, manner and voicing).[1]

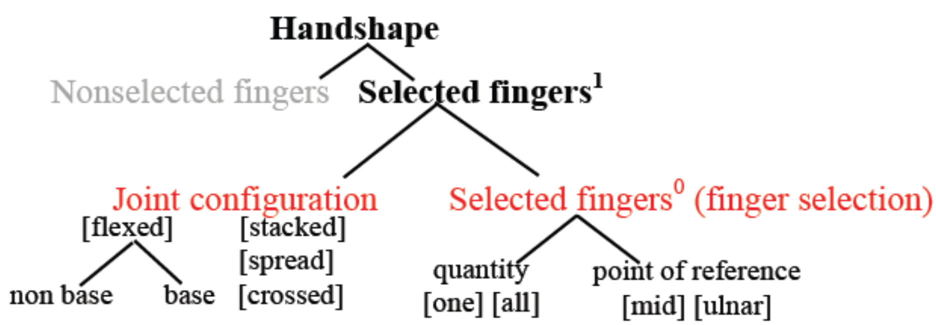


Figure 2. Joint configuration and finger selection in the handshape structure of the Prosodic Model (Brentari 1998).

The features of the Prosodic Model (Brentari 1998) involved in *finger selection* are the *quantity* and *point of reference* features (see Figure 2). The quantity features [one] and [all] specify how many selected fingers there are — one finger ([one]), two fingers ([one] dominates [all]), three fingers ([all] dominates [one]), or all fingers ([all]). The point of reference features [ulnar] and [mid] specify which side of the hand the selected fingers refer to: the default is the radial surface of the hand (index finger side), if the selected fingers refer to the middle or pinky finger side of the hand, it is specified as [mid] or [ulnar], respectively. The relevant features involved in joint configuration in the Prosodic Model (Brentari, 1998) are [flexed], which can apply to the base (knuckle) or non-base (interphalangeal) joints of the hand, as well as [spread], [stacked], and [crossed] (see Figure 2). The feature [flexed] plus the structures for *base* and *non-*

[1] We use the handshape font (e.g.,) to indicate handshapes. When used for *individual handshapes*, the image is a picture of a particular hand. When this font is used to represent *finger groups*, the image stands for a category of handshapes. In these cases, the term "finger group" will precede the image (i.e., "finger group "), and the image will picture a handshape with extended fingers, without the thumb. For example, the finger group represents the set of handshapes that includes the range of configurations with the index and middle finger selected: , , , , , , and .

base joints generate seven aperture positions from fully closed to fully open: fully closed, flat closed, curved closed, flat open, curved open, bent, and fully open.

1.2.1. Handshape complexity

The criteria for determining handshape complexity in terms of selected finger group and joint configuration is based on a number of factors, including frequency (Hara 2003; Eccarius & Brentari 2008), complexity of structure in terms of the number of branches and features in the phonological structure as described above, and age of acquisition (Boyes Braem 1990). In general, higher finger group complexity indicates a larger and more adult-like inventory of handshapes in acquisition (Marentette & Mayberry 1990). Examples of low, medium, and high complexity handshapes for both joint configuration and finger selection are given in Figure 3.

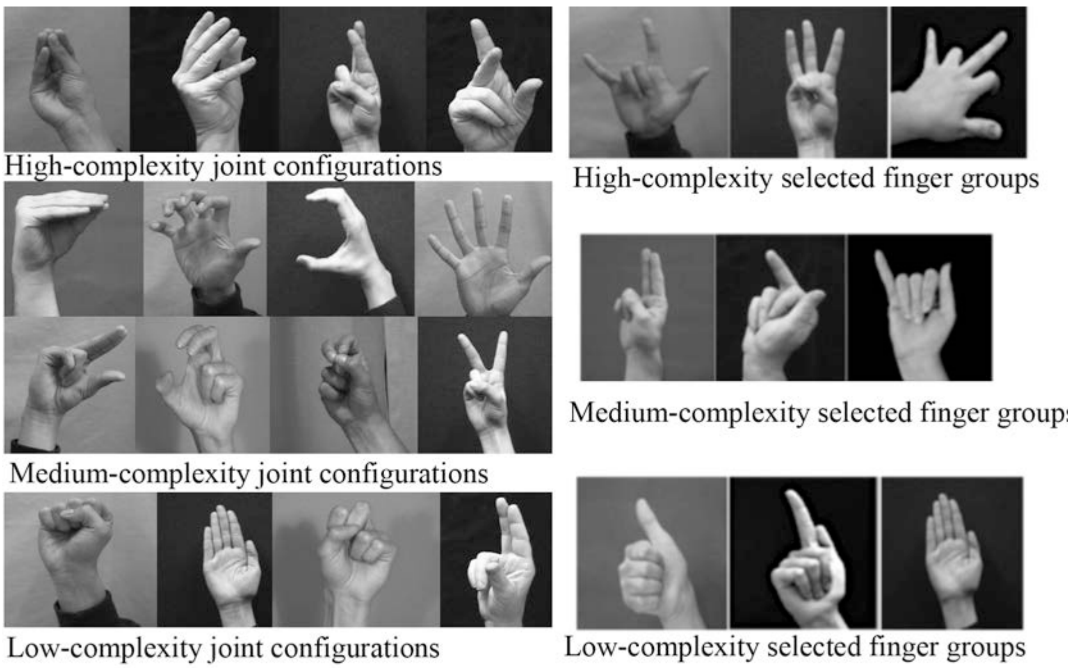
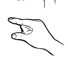
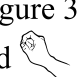


Figure 3. Examples of handshapes exhibiting different levels of joint complexity (left) and finger group complexity (right). The handshapes illustrating joint configurations are all variants of the B-handshape, with all of the fingers selected, or the U-handshape, with two fingers selected. The handshapes illustrating finger group complexity have fingers that are fully extended (selected), with the closed fingers being unselected.

1.2.1.1. Joint Complexity. The *low joint complexity* handshapes are the most frequent—fully extended or fully flexed (e.g.,  is a fully open handshapes and  is a fully closed handshape (Figure 3, left, bottom)). These are also among the earliest handshapes acquired by children learning ASL acquisition (Boyes Braem 1990) and British Sign Language. (Morgan, Barrett-Jones & Stoneham 2007). The most complex joint configurations are the most infrequent, the latest acquired, and the least frequent cross-linguistically (Geraci, Aristodemo, Coppola, Jordan & Brentari 2015)—stacked and crossed (e.g.,  [stacked] and  [crossed] (Figure 3, left, top)). The other joint specifications—flat closed , Flat open  curved closed  , curved open , bent . and spread  handshapes—are all designated medium complexity handshapes for our purposes here (Figure 3, left, middle).

1.2.1.2. Finger group complexity. Likewise, handshapes with *low finger group complexity* (Figure 3, right, bottom) are the most frequent cross-linguistically, are among the earliest acquired by native signers, and have the simplest phonological representation. They include the groups with all fingers (finger group), the index finger (finger group), and the thumb (finger group). These finger groups account for a high proportion of handshapes in ASL (81%) and in many other sign languages as well (Hara 2003). *Medium finger group complexity* handshapes (Figure 3, right, middle) include one additional structural elaboration: either a second selected finger on the radial (thumb) side of the hand (the default side), as in finger group , or a single selected digit that is not on the radial side, as in the pinky or middle finger groups and . *High finger group complexity* handshapes (Figure 3, right, top) include all remaining finger groups, which are less frequent and have more complex phonological structures.

1.3. Properties of Handling and Objects Handshapes: Morphophonology

Object and Handling classifier handshapes might or might not be paralleled by a corresponding phonological pattern. Using joint configuration as an example, let us consider a hypothetical situation in which a given sign language were to use the following set of handshapes as Object classifier handshapes—. This set would not only be a morphological class, but would also form a phonological class, because the selected fingers in each handshape share a phonological property; namely, they are all *fully open* ("extended"). If a signer of this sign language were to encounter new handshapes, such as or , these would be predicted to belong to the 'Object' class because of this phonological generalization. In contrast, if a second hypothetical sign language were to use this set of handshapes for whole entity classifiers—— the set could still be a morphological class, but it would not form a phonological class, as there is no common joint property that the handshapes share (see Figure 4); that is, the handshapes in this class would mark a specific class of meanings (whole entities), but would lack a corresponding phonological property that unifies them. In this second case, a signer could not predict from the handshape structure the morphological class to which it belongs.

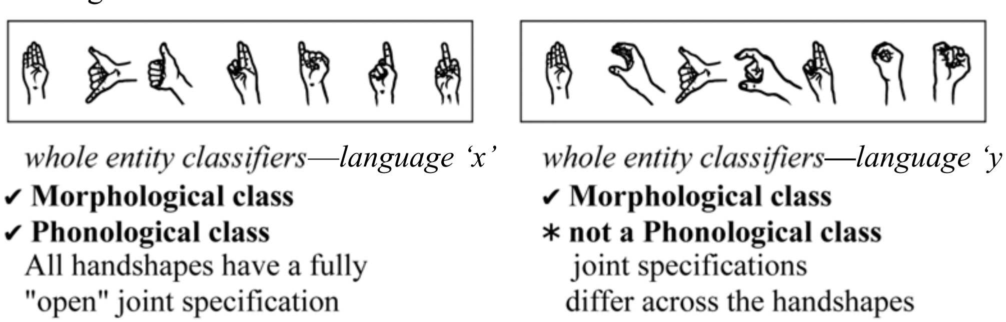


Figure 4. A group of hypothetical handshapes that would constitute a morphological and phonological class (left) and another group that would constitute only a morphological class (right).

Spoken languages also exhibit cases that are both phonological and morphological. For example, Arapeshan (Fortune 1942; Dobrin 1997), the singular and plural forms of gender class morphemes are generally paired with one another and the plural form typically has more phonological complexity than the singular form (4). This phenomenon is comparable to the phenomena we are studying in Object and Handling handshapes: there is clear systematic variation at the morphological and phonological levels but the morphology and phonology change together rather than independently.

(4) Arapeshan gender marking (cf. Dobrin, 1997)

	Gender Class	Singular	Plural
a.	I	ahory**by** ‘knee’	ahory**bys** ‘knees’
b.	VI	lawa**n** ‘tree snake’	lawa**nab** ‘tree snakes’
c.	XI	ali**t** ‘shelf’	ali**tog** ‘shelves’

Two morphophonological sign language handshape patterns of the sort described above pertain to finger complexity and joint complexity. Both were first observed by Eccarius (2008) and Brentari and Eccarius (2010) for three historically unrelated sign languages: ASL, Swiss German Sign Language (DSGS), and Hong Kong Sign Language (HKSL). Selected finger complexity was higher in Object Handshapes and lower in Handling handshapes, and Joint complexity was higher in Handling handshapes and lower in Object handshapes. While not every Handling handshape has lower finger group complexity and higher joint complexity than every Object handshape, these generalizations about the average complexity for each handshape class can predict where new entries into the system belong morphologically. One of these patterns—finger group complexity—was later studied in a larger, more controlled elicitation study in ASL and LIS (Brentari et al. 2012). In the current study we seek to replicate these findings, as well as add the dimension of joint complexity.

Shifting now to language emergence, Brentari et al. (2012) also demonstrated that the signers’ pattern in LIS and ASL (again in finger complexity only) differs from that of hearing people's gestures in Italy and the US, respectively. In gesture, a pattern opposite to that of the sign languages was observed: Object handshapes exhibited lower finger group complexity and Handling handshapes showed higher finger group complexity. Importantly, adult homesigners in Nicaragua exhibited a pattern that is closer to that of the sign language groups, suggesting that this form-to-form relationship occurs quite early in the emergence of language and that the sign language pattern was arrived at via a systematic process of phonologization. Furthermore, a longitudinal study of a single child homesigner over a five-year period confirmed this finding; in this young homesigner, sign language-like finger complexity appeared between the ages of 11 and 12 years (Coppola & Brentari 2014).

In the following two investigations we use a controlled elicitation task with sixty-nine adult and child participants, including deaf signers and hearing gesturers from four countries: Italy, the US, China, and Nicaragua, to address the following questions.

i) Are these patterns robust across sign languages, and truly different from that of local gestures? Specifically, are joint and finger group complexity used to form phonological oppositions between meaningful handshape types (i.e., Handling and Object) within a system?

ii) Are there crosslinguistic differences among the sign groups, and particularly, to what degree are these patterns evident in a newly emergent sign language?

iii) Are there cross-cultural differences among the gesture groups?

iv) Are these patterns evident in child language? If so, are they acquired before or after the corresponding morphological system is in place?

v) Are there patterns shown by participants in specific countries that might indicate a general gestural competence shared by both gesture and sign language?

2. General Methods

The stimuli, data collection and coding procedures are the same for all three studies, and are the same as those used in Brentari et al. (2012). They will be described here in a general methods section. The participants for each study will be described separately in each of the studies.

2.1. Stimuli

The stimulus items were drawn from a set of 131 photographs and short videos (henceforth vignettes), each of which featured one of eleven object types: toy airplanes, books, cigars, lollipops, marbles, pens, strings, tapes, television sets, and tweezers. The actual objects depicted in the stimulus clips exhibited a range of colors, shapes, and sizes. Each object type was portrayed in 10 conditions: 5 depicted a stationary object or an object moving on its own without an agent, and 5 depicted an object being moved by the hand of an agent (Figure 5). Not all items were collected from all groups, and because we will be comparing 14 different groups across both studies, we confine our analyses to a set of 31 stimulus items that were collected from every subject in each of the 14 groups: the full set of conditions for the objects airplane and lollipop, plus all of the objects in the condition where the object was falling from the table.

Scenes without an agent	**Scenes with an agent**
1. [object] on table	6. Put [object] on table
2. [object] on table upside down	7. Put [object] on table upside down
3. Multiple [objects] on table (regular arrangement in row/s)	***8. Put multiple [objects] on table (regular arrangement in row/s)***
4. Multiple [objects] on table (random arrangement)	9. Put multiple [objects] on table (random arrangement)
5. [object] falling	10. Demonstrate function of [object]

Condition 3: Airplanes in a row *Condition 8: Put airplanes in a row*

Figure 5. Description and examples of stimulus objects and conditions. The pictured conditions (3 and 8) are the ones in bold italics above.

2.2. Procedures

Gesturers were instructed to "watch each video and describe what you see using your hands and without using your voice." Signers were instructed in their respective sign language to "watch each video and describe what you see."[2] Data collection sessions were videotaped, and the video

---

[2] This task is also used with homesigners, as reported in other studies (Brentari et al., 2012, Coppola & Brentari, 2014, Goldin-Meadow, Brentari, Coppola, Horton & Senghas 2015), necessitating minimal instructions; for consistency instructions were minimal with all groups.

files containing the participants' responses were transcribed using ELAN (Crasborn & Sloetjes 2008).

2.3. Coding

A given trial could elicit multiple signs or gestures. Most signers first labeled the object in the vignette with a noun, before producing one or more verbs (containing a classifier affix) to describe the event. As our focus is on the event description, we did not include these nouns in our analyses. To make the comparable cut for the gesturers, we segmented their responses into gestures used to label the object (typically gestures produced on the body or in neutral space, that is, without reference to a specific location) and gestures used to describe the event or spatial arrangement shown in the vignette (gestures that moved or were situated at a particular location). This type of distinction could be made without difficulty, given that we were using a controlled task. We analyzed only the signs or gestures that expressed the state or event shown in the vignette. Each handshape was first coded in terms of the class of handshape to which it belonged, regardless of the stimulus: *Handling Handshapes* represented the manipulation or handling of the object; *Object Handshapes* represented the whole object, part of the object, or physical characteristics, such as size and shape, of the object. Handshapes that were not relevant to our analyses and were thus excluded were: the index finger or neutral handshape used to trace the object's path or indicate its location; the whole body used to substitute for an object in motion (e.g., falling off the chair to indicate the object falling); or lexical verbs (such as FALL), rather than classifier predicates (relevant only to signers).

Each handshape was then transcribed according the notation system developed in Eccarius and Brentari (2008), and assigned separate *joint* and *finger group complexity* scores using the criteria described above in Section 1.2.1: Low (1), medium (2), or high (3). A handshape was given an extra point each for complexity of fingers or joints if there was a change in the dimension in question in a single gesture or sign. For example, if the handshape changed from one joint configuration to another— (V-handshape) to  (R-handshape), or  (B-handshape) to  (B[flat]-handshape)—an extra point of joint complexity was added. If the gesture or sign began using all of the fingers and ended in a handshape using only one finger—e.g.,  (B-handshape) to  (1-handshape); or  (1-handshape) to  (V-handshape)—an extra point of finger group complexity was added. Thus, values for finger group or joint complexity ranged from 1 to 4.

The interlocutor was either a native signer or speaker, or in the case of NSL, a peer from the same cohort. For each study, annotation was performed by a team of trained annotators based in the laboratory of the first author. All had at least 3 months of training on the coding system, until they reached a threshold of reliability on a standard set of items. Reliability was assessed on the coding of specific handshape form (i.e., which of over 100 possible handshapes was the best match for the produced handshape) and for handshape type (Object, Handling, or neither (e.g., a point or lexical verb)). Coders were assessed on data from one participant from each group, for one stimulus object (e.g., airplane). Agreement between coders was at least 90% for both handshape form and handshape type.

3. Study 1: Adult Sign Language vs. Gesture Groups (four countries)

In Study 1 we ask whether the patterns of finger group and joint complexity are different across languages and cultures in adults. We selected Italy, the US, China, and Nicaragua for comparison, for several reasons. Regarding gesture, the gesture systems of Italy and Nicaragua include a rich set of types of manual gestures (including pragmatic and emblematic gestures) and have been called “gesture-rich” cultures, compared to the US (Kendon 2004) or China. If some gesture systems could be found to show a sign-like pattern, we might expect it to be within such a culture.

Regarding the sign languages chosen, we sought to compare sign languages that are completely unrelated (LIS, ASL vs. CSL), that may be related (LIS, ASL), and that differ in their historical depth (ASL, LIS, CSL vs. NSL). The Shanghai variety of CSL is totally unrelated to ASL, NSL, and LIS. The first school for the deaf in Shanghai dates from 1892 (Fischer & Gong 2010). ASL and LIS are remotely related, and likely both share some influence of the sign language used in France by means of a network of European clergy who established schools in the first half of the 19th century (Quer et al. 2010). The historical contexts are quite a bit different, however. Gallaudet traveled to Paris and brought back Laurent Clerc (a signer of Langue des Signes Française) to assist him in establishing the first American school, and Clerc’s presence had an effect on ASL as it emerged (Lane 1984), while Silvestri did not bring a Paris school graduate back to Italy. Historians, therefore, infer that Silvestri’s methods were applied more directly to what Italian signers were already using at the time (Corazza 1993; Quer, et al. 2010).

NSL is a newly emergent sign language that arose naturally within a social community of deaf children and adolescents in Managua, the capital of Nicaragua (Kegl & Iwata 1989; Senghas 1995). Prior to the 1970s, deaf individuals in Nicaragua had few opportunities to interact with one another. Most deaf individuals were isolated in their homes, and the few schools and services available served small numbers of children and adolescents, without leading to extensive social contact outside of school hours. In this context, no sign language emerged, evidenced by the lack of a shared language in deaf adults over the age of 50, even today. These homesigning individuals have neither a language community nor a language model. In the late 1970s and early 1980s, rapidly expanding special education programs in Managua brought many deaf individuals together for the first time. Initially, approximately 50 deaf children were enrolled; this number increased to over four hundred by the mid-1980s (Polich 2005). Although all instruction at that time was conducted in spoken Spanish, students were able to freely communicate with each other using gestures. As they interacted socially on school buses, in the schoolyard, and later in their homes, they converged on a common system of signs and a new sign language was born. At this stage, these signers had a community but not language model, and are often referred to as Cohort 1 signers. The language continued to develop and change, increasing in grammatical complexity as new waves of children entered the community each year and learned to sign from older peers (Senghas & Coppola 2001; Senghas, Kita & Özyürek 2004) with the benefit of both a language community and a language model to Cohort 2 signers and beyond. We chose Cohort 2 signers for our study because they are the “earliest” group with both a language model and a linguistic community. We wanted the NSL signers to be as similar to the ASL, LIS, and CSL signers as possible except for the factor of language age, so this was the optimal comparison group.

3.1. Participants

Forty-four adults participated in this study: 22 signers and 22 gesturers. For ASL, LIS, and CSL, all signers were native users of the target language (having at least one Deaf signing parent), use their respective sign language as their primary language, and are active members of their respective Deaf communities. The six ASL signers are from the Midwestern area of the United States (age range 27-56 years, *M*=41); the six LIS signers are from the greater Milan area (23-39 years, *M*=33); the five signers of CSL are from Shanghai (27-32 years, *M*=30), and the five signers of NSL are from Managua (19-24 years, *M*=22). The NSL signers had all been first exposed to NSL between 4 and 6 years of age. They are also active participants in the Deaf community.

Twenty-two adult, hearing gesturers also participated: six Italians from the Tuscany region (20-29 years, *M*=24), six Americans from the Midwestern area of the United States (20-25 years, *M*=23), five Chinese individuals from Shanghai (21-31 years, *M* =26), and five Nicaraguans from Estelí, a city in the north of Nicaragua, (18-30 years, *M*=22). None of the hearing gesturers are familiar with a sign language, nor do they have any deaf members in their families.

3.2. Analysis and Results

Study 1 asks whether signers and gesturers use joint and finger complexity differently for Object and Handling handshapes and whether there are important crosslinguistic differences (for the sign groups) or cross-cultural differences (for the gesture groups). The overall dataset contained 2537 data points from the 44 participants. Multiple gestures/signs within a single event description portion were included in the analysis. Two linear mixed-effects models were used (Baayen, Davidson, & Bates 2008), one with joint complexity as the dependent variable and one with finger group complexity as the dependent variable. In each model, Type of System (Sign language, Gesture), Handshape Type (Object, Handling), and Country (United States, China, Italy, Nicaragua) were treated as fixed effects. Random intercepts for Participant, Stimulus Object, and a by-Stimulus-Object random slope for the three-way interaction of Type of System x Country x Handshape Type were included as random effects (Barr 2013). No correlation between the random effects was assumed. The difference in complexity between Object handshape and Handling handshape (a factor internal analysis) was also analyzed to see if there was a significant difference in the way that the two types of handshape were used in each group for joint and for finger group complexity. We used the R statistical computing environment (R Core Team 2014) and lme4 (Bates, Maechler & Bolker 2014) to perform the analyses. In all F tests, the Kenward-Roger approximation method was applied to adjust the denominator degrees of freedom.[3] The Benjamini-Hochberg procedure (Benjamini & Hochberg 1995) was applied to account for multiple testing in post-hoc comparisons. The results of both the joint and finger complexity analyses are shown in Figure 6.

[3] In all F tests, the Kenward-Roger approximation method, implemented in pbkrtest (Halekoh & Højsgaard, 2014) was applied to adjust the denominator degrees of freedom.

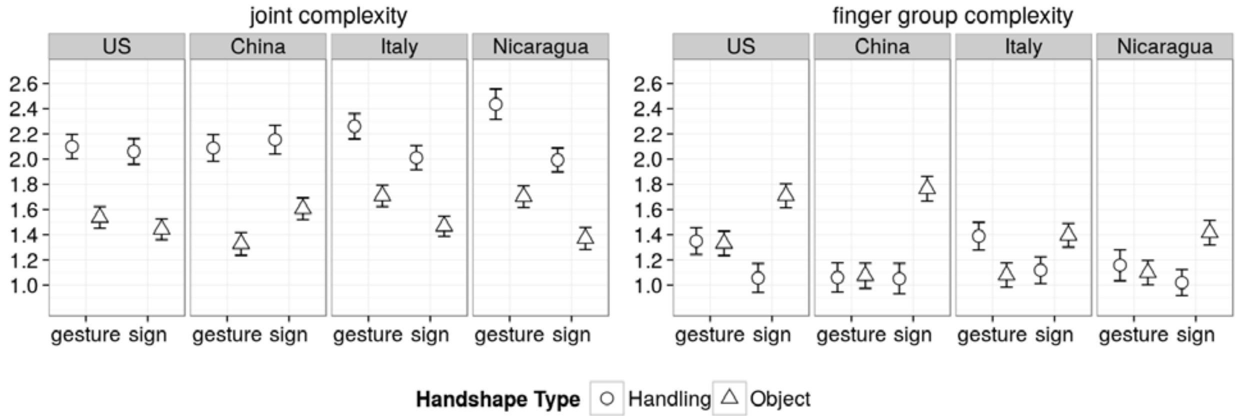


Figure 6. Adult joint and finger group complexity in the US, China, Italy, and Nicaragua. Estimated joint complexity (left) and finger group complexity (right) for each group, with standard error bars. The symbol (circle for handling handshapes or triangle for object handshapes) indicates the mean. Because these are estimated values provided by the model, values can be less than 1, which was the minimum finger or joint complexity value in our system.

3.2.1. Joint Complexity

Joint complexity showed significant effects for Type of System (F=6.315, ndf=1, ddf=71.670, p <0.01), where the gesture groups had higher joint complexity than the sign groups, and for Handshape Type (F=241.091, ndf=1, ddf=438.150, p <0. 0001), where Handling handshapes showed higher joint complexity than Object handshapes. There was also an interaction of Type of System and Country (F=4.917, ndf=3, ddf=71.630, p= 0.004), where the gesture group had higher joint complexity than the sign group in Nicaragua, Italy, and US, while the sign group had higher joint complexity than the gesture group in China.

Post-hoc pairwise comparisons suggest that all sign language and gesture groups showed significantly higher joint complexity for Handling than Object handshapes (all p's <0.0001), and the Chinese gesture group had lower joint complexity than the Italian and Nicaraguan gesture groups in Object handshapes (p=0.013). There were no other significant effects or interactions. Examples of handshapes from the adult groups with high joint complexity are shown in Figure 7.

Adult Chinese (Shanghai) signer producing an Object handshape with **High joint Complexity**

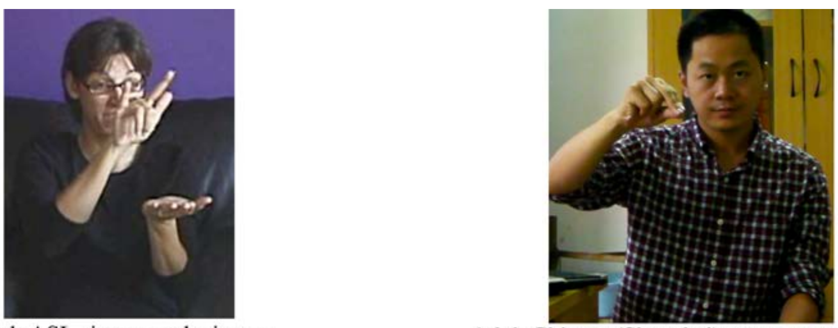
Adult Nicaraguan gesturer producing a Handling handshape with **High joint complexity**

Figure 7. Handshapes produced by adults with high joint complexity showing a set of tweezers about to fall by a Chinese signer (left) and showing a set of planes being put on a table by a Nicaraguan gesturer (right).

3.2.2. Finger Group Complexity

There was a significant difference for Type of System, where signers had higher finger group complexity than gesture groups (F=5.597; ndf=1; ddf=153.017; p=0.02), and for Handshape Type, where Object handshapes showed higher finger complexity than Handling handshapes (F=22.415; ndf=1; ddf=393.386; p<0.0001). There was a significant interaction between Handshape Type and Type of System (F=50.631; ndf=1; ddf=362.762; p<0.0001), where Object handshapes showed higher finger complexity than Handling handshapes, specifically for sign groups. In addition, the interaction between Handshape Type and Country was significant (F=4.152; ndf=3; ddf=361.656; p<0.01), where Object handshapes had higher finger complexity than Handling handshapes in China, US, and Nicaragua, but the Handling handshape had higher finger complexity than the Object handshape in Italy.

Post-hoc pairwise comparisons suggest that all of the sign groups showed higher finger group complexity in Object handshapes than in Handling handshapes (all p's < .05). The Italian gesture group also showed a significant difference between Object and Handling handshape finger group complexity, (p = 0.02), but in the opposite direction: Handling handshape finger group complexity was greater than Object handshape finger group complexity. Post-hoc pairwise comparisons of finger group complexity, specifically for Object handshapes, also showed significant differences between CSL and LIS, between CSL and NSL, between ASL and LIS, and between ASL and NSL (all p's < 0.05). There were no other significant effects or interactions. Examples of handshapes from the adult groups with high and medium finger group complexity are shown in Figure 8.



Adult ASL signer producing an Object handshape with **High finger group complexity**

Adult Chinese (Shanghai) gesturer producing an Object handshape with **Medium finger group complexity**

Figure 8. Handshapes produced by adults, exhibiting high finger group complexity by an ASL signer showing an airplane about to turn upside down (left), and medium group complexity by a Chinese gesturer showing a set of tweezers about to fall (right).

3.3. Discussion: Study 1

The goals in Study 1 were to determine whether different types of systems (sign language vs. gesture) showed different patterns of joint and finger complexity, as well as differences among the sign groups, among the gesture groups, or among the countries. Three major findings emerged. First, signers' handshapes are not more complex than those of gesturers overall, but in sign languages the complexity is distributed more equally across the two handshape types. Sign languages reduce the amount of joint complexity that is sufficient to capture the number of categories the language requires and no more. The distribution of their complexity has become more balanced and is directed in a systematic way towards the two handshape types—joint complexity is associated with Handling handshapes and selected finger complexity with Object handshapes. Second, signers and gesturers have the same pattern with regard to joint complexity—higher in Handling handshapes, lower in Object handshapes. In contrast, the finger group complexity patterns differ between the two groups—signers show higher finger complexity in Object handshapes while gesturers do not. Third, the emerging sign language, NSL, exhibits the same pattern as the three well-established sign languages.

Before discussing the quantitative results in detail, there is an interesting observation worth noting about production that included a change in joint or finger group complexity. Although a sign in ASL may undergo a change in joint specification and still be well formed, there is a stronger tendency in the sign groups not to change the joint value in their productions compared with the gesturers (average .08 for sign groups; average .21 for gesture groups;). In other words, the gesture groups more often produced forms consisting of an open  or flat  form changing to a stacked or closed  form, which resulted in an additional complexity point for joints. With regard to finger group complexity, ASL has a restriction on changing from one finger group to another within a sign (Sandler, 1986, Brentari 1998). For example, a high Object handshape finger complexity form such as   or  cannot change to a , a change which would gain that form an extra complexity point. Here we see that neither signers nor gesturers produced forms with changes in finger group very frequently (average 1% for sign groups; average 4% for gesture groups); nonetheless, for every pair of groups by country, the sign group produces fewer changes than the corresponding gesture group.

3.3.1 Joints

Higher joint complexity occurs in Handling than Object handshapes in all groups. We suggest that the affinity between joint complexity and Handling handshapes is gestural rather than linguistic, as well as iconic, and that it may also be the starting point for phonologization in signers. In other words, the manual modality has a very strong affinity between the use of joints to show manipulation of objects, and gesturers access iconic gestures via action (Piaget, 1952), where hands represent hands, in hand-as-hand iconicity. Though this study concerns adult data, the argument that handling handshapes are associated with action accords with Marentette and Nicoladis (2011), who found that as soon as children become sensitive to the iconicity inherent in gesture, their default assumption is that gestures are action associates; that is, an "action bias" in iconicity appears quite early in acquisition. We will see if this bias is already in place in the child participants in Study 2.

The gesture groups show some significant differences among them. The Nicaraguan and Italian gesture groups show higher joint complexity, particularly in Handling handshapes, than the Chinese gesturers, showing that even if there are broad similarities across all gesture groups, there are also differences among them at a finer-grained level.

3.3.2 Selected finger groups

Of the properties analyzed in this work, there are no patterns of finger group complexity that signers and gesture groups share. All sign groups show higher finger group complexity in Object than Handling handshapes, but gesturers do not show this pattern. One of the striking findings is that NSL shows the same overall pattern as the more established sign languages, so it is clear that this restructuring happens quite early in the emergence of a language. This concurs with the findings of Brentari et al. (2012) for ASL and LIS, as well as the findings with four adult homesigners, and of Coppola and Brentari (2014), with a single child homesigner studied longitudinally (ages 7-12 years).

Another interesting finding is that, focusing on the sign groups, the post-hoc comparisons suggest that CSL and ASL pattern in ways that are more similar to each other, and that LIS and NSL also pattern together. Further analysis is needed on the potential typological groupings of sign languages based on such phonological differences.

Focusing on the gesture groups, only the Italian gesture group showed a significant difference between Object and Handling handshapes, but in the opposite direction than the sign groups; i.e., higher finger complexity in Handling handshapes than in Object handshapes. This helps to further confirm and clarify the result found in Brentari, et al. (2012), where gesturers also had a significantly higher degree of finger group complexity in Handling than Object handshapes. It appears that in many gesture groups, there is not enough finger group complexity in any handshape type for this difference to be manifest. In other words, gesturers often will not display any finger group complexity, but if they do, it is predicted to appear in Handling handshapes, and to align with the results from the Italian gesture group. It appears that the link between action and gesture leads gesturers to channel all of their complexity into Handling handshapes, and to virtually ignore complexity in Object handshapes.

On a final note, it is quite interesting that the countries where gesture groups pattern together on joint complexity (Italy and Nicaragua) are the same as those sign groups that pattern together with regard to finger group complexity. These correlations across country would be interesting to pursue in future work, because they hint at some common properties across country that have not been uncovered with this task.

In summary, we are not arguing that sign languages have more complex handshapes than gesturers overall; rather, our general findings support the view that sign languages undergo a fairly radical restructuring of the surrounding gesture system, resulting in a qualitatively different, predictively patterned system. Iconicity is not ignored, but is shaped into a system that can accommodate a wider range of meanings, and phonological contrasts for those meanings—in other words, an efficient system that does not excessively tax the production and perceptual system. By using the gesture groups for comparison, we see that phonologization in the sign groups involves losing some of the joint complexity in Handling handshapes and increasing finger complexity in Object handshapes, and we would argue that since sign languages have both hand-as-hand and hand-as-object iconicity, the overall morphophonological pattern of sign languages is to create a division of labor such that Handling handshapes are associated with joint complexity, and Object handshapes come to be associated with finger group complexity.

4. Study 2: Child Signers and Gesturers in Italy, the US, and Nicaragua

This brings us to the question of the origin of these patterns in acquisition. The aim of Study 2 is to compare children's patterns of finger complexity to those found in adult signers and gesturers from the corresponding groups. Do the two types of features (joint and finger selection) travel together or separately? Do the different handshape types arise in response to a need to mark different morphological types, in this case, the different categories of morphological classifiers? Or does the variety of forms emerge first, available to be mapped to the distinctions in morphology as they are acquired? That is, which comes first in acquisition, the phonology or the morphology? This is a question about how a child learner breaks into the system. We know from previous work that the distinction between Handling and Object handshapes as markers of agentive vs. nonagentive clauses appears sometime between age 7 and 9 years of age (Schick, 1987; Brentari et al., 2013). We turn to child signers and gesturers in Italy, the US, and Nicaragua, to see if the pattern of handshape complexity is evident early, even before the morphological contrast associated with Handling and Object handshapes is typically fully acquired.

All children studied were immersed in their respective sign languages for four to six years prior to testing. Deaf Nicaraguan children are typically first exposed to their sign language when they enter school, so they were tested at age 10, having 4-6 years' exposure to NSL, comparable to the number of years of exposure of the 3- to 6-year-old LIS and ASL children. This age range was chosen because, by this time, the acquisition of handshape from the phonological point of view is thought to be complete (Boyes Braem 1981, Marentette & Mayberry 2000); however, the acquisition of the agentive/non-agentive clause distinction is ongoing during this period in ASL (Supalla 1982; Schick 1987, Brentari, Coppola, Jung & Goldin-Meadow 2013; Brentari, DiRenzo, Keane & Volterra 2015).

From a purely phonological point of view, the acquisition of handshape follows a time course from approximately 12 to 48 months that is best explained by the principles of ease of articulation and ease of perception (Boyes Braem 1990; Conlin, Mirus, Mauk & Meier 2000; Marentette & Mayberry 2000; McIntire 1977). Handshapes that are easier to produce and perceive are acquired earlier than handshapes that are more difficult to produce and perceive. Kantor (1980) and Fish, Morén, Hoffmeister & Schick (2003) helped to refine these findings of handshape acquisition in classifiers, showing that handshape complexity alone cannot explain children's classifier handshape errors. They concluded that other factors may also be involved, particularly the use of the same handshapes within a second morphological system (in the productive classifier system), as well as within the phonological system (in core lexical signs). Kantor (1980) investigated the acquisition of complex handshapes, such as , and found that they are used first in core lexical items and only later in classifier predicates.

There is an extensive literature on the general acquisition of classifier predicates in ASL. This previous work shows that classifier predicates are learned between the ages of 3;0 and 9;0 (years; months), morpheme by morpheme (rather than as unsegmented wholes; Ellenberger & Steyaert 1978; Newport 1981; Supalla 1982; Newport & Meier 1985; Lillo-Martin 1999; 2009; Singleton & Newport 2004). The specific morphosyntactic system associated with the agentive/non-agentive opposition addressed here first appears between ages 4 and 6 years, but is not fully mastered until ages 7;0-10;0 in ASL (Schick 1987, Brentari et al. 2013).

4.1. Participants

Twenty-five children (11 signers and 14 gesturers) from Italy, the United States, and Nicaragua participated. Four child signers from Italy (LIS) ranged in age from 3;10-6;0 (*M*=5;2) and attended a bi-lingual, bi-cultural educational program in Rome. Two ASL signers from the greater Indianapolis area participated once per year for three years (ages 4;1-6;4); their data was pooled across testing sessions.[4] The third ASL signer participated once (4;4). All three were attending the Indiana School for the Deaf, a bi-lingual, bi-cultural educational program in which the goal is for children to master both ASL and (written) English. All ASL and LIS signers had Deaf signing parents and used their respective sign language as their primary language. The four NSL signing children were from Managua (ages 10;1-10;8, *M*=10;5); they were chosen specifically because they have had 4-6 years of exposure to NSL, and in this way are closest in

[4] These data were analyzed separately for each year and each subject. Finding no differences by year, the data were pooled.

language experience to the LIS and ASL child signers. They are Cohort 3 signers according to the description from Study 1; that is, they have both a linguistic community and a language model, and they had as their model signers from Cohort 2. The gesture groups consisted of three Italian children from Rome and one from the Tuscany region (ages 4;6-5;3, *M*=4;11), three American children from the greater Los Angeles area (ages 4;3-4;8, *M*=4;5), and seven children from Estelí, a city 2 hours north of Managua (5;0-10;8, *M*=7;4). None of the gesturing children had been exposed to sign language.

4.2. Results

The child data were subjected to the same analyses as those in Study 1, first alone (945 observations), and then combined with the adult data from the corresponding groups in the three countries (2975 observations). We again used a linear mixed-effect model to analyze the effects of Type of System, Country, Handshape Type, and Age on joint and finger group complexity. The results for both the joint and finger complexity analyses are shown in Figure 9.[5]

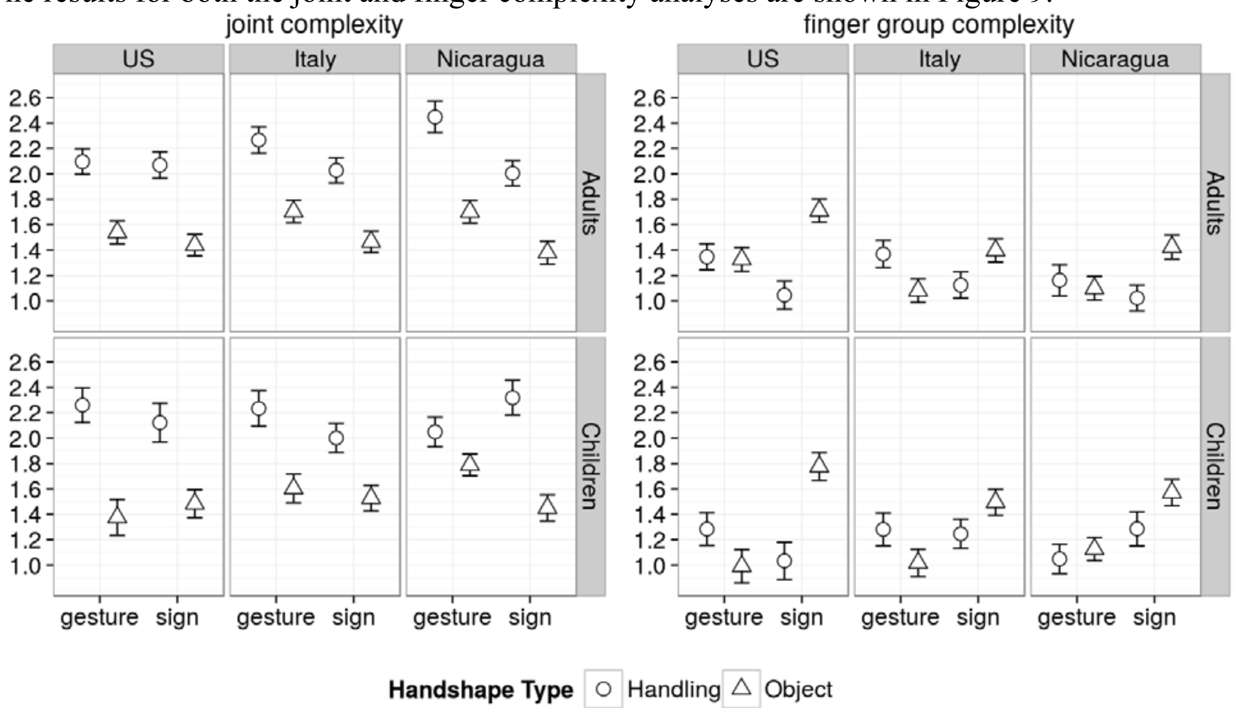


Figure 9. Child and adult joint and finger group complexity in the US, Italy, and Nicaragua. Estimated adult (top) and child (bottom) joint complexity (left) and finger group complexity (right) for each group with standard error bars. The symbol (circle for Handling handshapes or triangle for Object handshapes) indicates the mean..

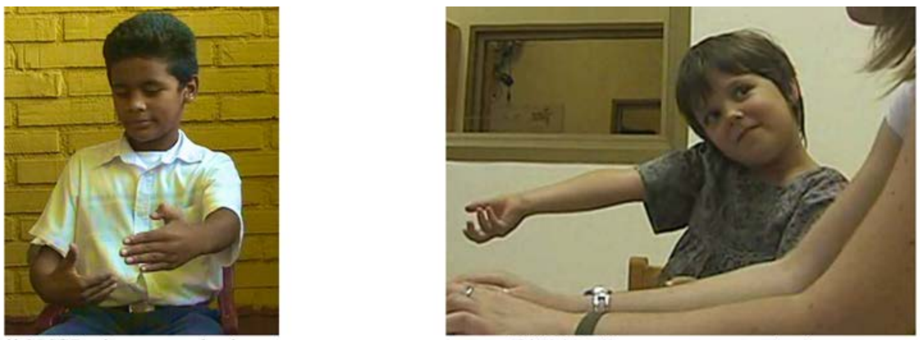
4.2.1. Joint Complexity

When the child data were analyzed alone, joint complexity showed significant effects for Handshape Type (F=101.793; ndf=1; ddf=328.422; p< 0.0001), with higher joint complexity for Handling than Object handshapes overall. In addition, there was a significant three-way interaction among Type of System, Handshape Type, and Country (F=5.266, ndf=2, ddf=265.545, p=0.0057); the complexity difference between Handling and Object handshapes was less in the Nicaraguan gesture group than in the sign group and greater in the US gesture

[5] The estimated means differ slightly in Study 1 and Study 2 because they are affected by the comparison groups.

group than in the sign group. Pairwise comparisons suggest that joint complexity was higher for Handling than for Object handshapes in all groups (all p's < .001).

When the combined data were analyzed (adults and children), joint complexity showed significant effects for Handshape Type (F=270.086, ndf=1, ddf=755.025, p<.0001), with higher joint complexity for Handling than for Object handshapes, and Type of System (F=8.760, ndf=1, ddf=82.950, p=.004), with higher joint complexity for the gesture groups than for the sign groups. In addition, there was a significant four-way interaction effect among Type of System, Handshape Type, Country, and Age (F=5.284, ndf=2, ddf=659.655, p=.005). Looking at Figure 9, this effect is apparently due to the Nicaraguan child and adult gesture groups, which show a more noticeable difference than the other child-adult group comparisons. Examples from the child groups of handshapes with high joint complexity are shown in Figure 10.



Child NSL signer producing a Object handshape with **Medium joint complexity**

Child Italian gesturer producing a Handling handshape with **High joint complexity**

Figure 10. Examples of handshapes showing two levels of **joint complexity**. A child NSL signer uses a **medium joint complexity** handshape to show a book on a table (left), and a child Italian gesturer uses a **high joint complexity** handshape to show a toy airplane being put upside down on a table (right).

4.2.2. Finger group complexity

When the child groups were analyzed alone, there was a significant difference for Type of System (F=11.715; ndf=1; ddf=35.262; p=0.001); where sign groups showed higher average finger group complexity overall than gesture groups, and for Handshape Type (F=6.988; ndf=1; ddf=314.352; p=0.008), where Object handshapes had higher finger complexity than Handling handshapes. There was a significant interaction of Handshape Type and Type of System (F=27.572; ndf=1; ddf=279.420; p<0.0001), with sign groups showing higher average finger complexity than gesture groups, specifically in Object handshapes. In addition, the three-way interaction among Handshape Type, Type of System, and Country was significant (F=3.489, ndf=2, ddf=266.059, p=0.032), with the ASL sign group showing a greater difference between Handling and Object handshapes than the Nicaraguan or Italian sign groups. Pairwise comparisons revealed that finger group complexity was higher for Object than for Handling handshapes in each of the three child sign language groups (p<0.05), but not in the three child gesture groups.

When combined with the adult groups, the main effects of Type of System and Handshape Type were significant: finger complexity was higher in the sign group than in the gesture group (F=11.971, ndf=1, ddf=126.065, p=.0007); and higher in the Object than in the Handling handshapes (F=15.284, ndf=1, ddf=653.678, p=.0001). There were significant two-way interactions between Type of System and Handshape Type (F=64.348, ndf=1, ddf=597.916, p<0.0001) and between Type of System and Age (F=5.230, ndf=1, ddf=126.034, p=0.024), where the difference between child gesture and sign groups was larger than between adult gesture and sign groups; and between Handshape Type and Country (F=5.272, ndf=2, ddf=591.987, p=0.005). There was also a three-way interaction among Type of System, Handshape Type, and Country (F=4.314, ndf=2, ddf=592.264, p=.014). Examples from the child groups of handshapes with medium and low finger group complexity are shown in Figure 11.

Child LIS signer producing an Object handshape with **Medium finger group complexity**

Child American gesturer producing an Object handshape with **Low finger group complexity**

Figure 11. Handshapes produced by children showing a toy airplane on a table. The LIS signer uses a handshape with **medium finger group complexity** (left) and the American gesturer uses a handshape with **low finger group complexity** (right).

4.3. Discussion: Study 2

The productions of the children in Study 2 reveal important new information, beyond what we learned about adults in Study 1. First, finger group complexity shows a stronger effect of age than joint complexity. Specifically, there is an even greater difference in finger group complexity between the child gesture and sign groups than between the adult gesture and sign groups. This suggests that the finger group complexity pattern is still undergoing change between childhood and adulthood. In contrast, for joint complexity only the Nicaraguan gesture groups showed an effect of age. The similar use of joint complexity in gesture and sign suggests that it follows naturally as an extension of manipulating objects. Moreover, the joint complexity pattern evidently stabilizes earlier than the period studied here, a finding consistent with Marentette and Nicoladis (2011), who showed that the patterns of action bias in iconic association emerge between the ages of 2 and 4.

These results also indicate that the phonological patterns studied here are acquired in signing children prior to the morphosyntactic distinction of Handling handshape for agentive clauses and Object handshapes for non-agentive clauses. We know from previous research on first language (L1) acquisition of ASL that the use of Object and Handling handshapes to mark the morphosyntactic, agentive distinction in classifier constructions is not mastered until between 7 and 9 years of age (Schick, 1987, Brentari et al. 2013). The same 4-6 year old participants from the Brentari et al. (2013) study participated in the current study, and showed evidence of the phonological finger group complexity pattern.

Further evidence of this phonological distinction coming before the morphosyntactic one comes from language emergence. Coppola and Brentari (2014) found in a single child homesigner that the finger group complexity (phonological) pattern described here appeared in the homesigning child at 11;4, while the morphosyntactic pattern seen in adult signers was not present even at age 12;8. This dissociation indicates that these two aspects of the grammar are independent, even as they appear in the same handshapes, and that along these two dimensions phonology precedes morphology. It may be that the phonological distinction assists children in assigning the handling and object classifier handshapes to their appropriate category in later acquisition.[6]

Considering these findings, in future work it will be interesting to investigate the phonological distinction described here in core lexical noun and verb signs (Kantor 1980; Fish, et al. 2003) to see if the finger complexity difference found in such "frozen" signs exists there to the same (or a lesser or greater) degree than it does in the productive classifier handshapes in children.

5. General Discussion and Conclusions

Let us now return to the questions we asked in the introduction. We asked if these patterns are robust across sign languages, and truly different from that of local gestures, and we can answer that they are, in both adults and children. The signers phonologize both joint and finger group complexity differentially towards Handling and Object handshapes, maintaining a delicate balance between iconicity, ease of perception and production, and a balanced and predictive distribution. Importantly, we have found that adult NSL signers exhibit a pattern of higher finger group complexity in Object handshapes than in Handling handshapes, the same pattern found in adults who use LIS, CSL, and ASL—languages with much longer histories. In addition, we would argue that these properties are used to form phonological oppositions in signers, but not in gesturers, due to the lack of a double dissociation (division of labor) in gesture between joint and finger group complexity in Handling and Object handshapes,.

We have found that there are some differences among the sign groups and gesture groups, and it is possible that culturally shared gestural properties that both signers and gesturers have access to form the basis of these cross-cultural differences in both gesture and sign language, discussed further below.

We also asked if these patterns are evident in child language and, if so, whether they are acquired before or after the corresponding morphological system is in place. We found that the phonological pattern of finger group complexity is acquired prior to the morphosyntactic one associated with agentive/non-agentive distinction.

We can now consider the implications of these findings for acquisition, variation, and the emergence of phonology. We summarize our findings in the schema in Figure 12, with joint complexity results on the left and finger group complexity on the right. The nested squares at the top schematize the adult findings, and the age effects are given below those.

The figure is divided into three parts separated by the grey horizontal bars. Starting with the top portion, we see two main findings: the main effect for handshape type—that Handling handshapes have more joint complexity and object handshapes have more finger group complexity—and the main effect for Type of System—gesture groups exhibit higher joint complexity and signers exhibit higher finger group complexity. Crucially, there is no overall difference of complexity between gesture and sign if the two handshape types and two types of complexity are collapsed; both groups produce equally complex handshapes of one form or another.

---

[6] In child signers of LIS these two dimensions cannot be pulled apart, because Brentari et al. (2015) demonstrated that in the acquisition of LIS, the morphosyntactic, agentive-nonagentive opposition of Handling and Object handshapes appears between 3;11 and 6;1 (earlier than in ASL).

Effects	Joint complexity		Selected Finger Group complexity	
Handshape Type	Handling > Object		Object > Handling	
Type of System	Gesture > Sign		Sign > Gesture	
	Gesture	**Sign**	**Gesture**	**Sign**
Handshape Interactions	All groups same pattern		For Italy, Handling > Object	For all countries, Object > Handling
Country Interactions	Nicaragua, Italy > China			US, China > Italy, Nicaragua
Age Interactions	Nicaraguan Adults > Nicaraguan Children		Children show greater effect of Type of System (Sign > Gesture) than Adults	

Figure 12. Summary of findings for joint complexity (left) and finger group complexity (right).

In the middle portion, which indicates interactions of handshape type and specific groups, we see that all groups (gesture and sign) produce higher joint complexity in Handling handshapes, while only the sign groups show higher finger group complexity in Object handshapes. The finger complexity finding replicates the finding in Brentari et al (2012). In other words, once signers recognize that both Handling and Object handshapes offer different types of iconic possibilities and introduce "hand-as-object" iconicity, they differentially apply handshape features to each handshape type, produce higher finger group complexity overall, and significantly higher finger group complexity in Object than Handling handshapes, a pattern not observed among gesturers. This creates a division of labor in which high finger group complexity is associated with Object handshapes and then, in order not to exceed a threshold that would make handshapes too complex, has the effect of lowering their joint complexity with respect to the gesturers in Handling handshapes. These findings suggest that sign languages place a maximum on the overall handshape complexity for the language, likely in order to allow for efficiency in terms of perceptual contrast and ease of production, and therefore joint complexity decreases somewhat in order to avoid handshapes that are too complex to communicate rapidly and efficiently.

The middle portion of Figure 12 also shows specific differences among groups. The Nicaraguan and Italian adult gesture groups show higher joint complexity than the Chinese gesturers, and ASL and CSL sign groups show higher finger group complexity than LIS and NSL signers. In other words, the Nicaraguan and Italian sign and gesture groups pair up consistently with respect to differences, even if these differences are along different dimensions.

The two age effects are indicated in the bottom portion of Figure 12. First, the joint complexity pattern is already quite stable at this age, and shows only a weak effect of age between child and adult gesturers in Nicaragua. Second, children's finger complexity shows the same effect (but to a greater degree) of Type of System as the adult groups, whereby sign shows greater finger complexity than gesture.

We might therefore tentatively conclude that the shared joint pattern develops from interacting in the world via action, similar to Nicoladis and Marentette (2009), while finger complexity pattern is due to exposure to a sign language. Even though adults exhibit more finger complexity than children in gesture when collapsed across handshape type and country, only groups exposed to a sign language exhibit the sign language pattern.

5.1 When does a system become phonological?

In other work concerning the emergence of phonology in sign languages, Sandler, Aronoff, Meir & Padden (2011) have focused on the recently discovered, relatively isolated community of signers in Israel who use what has come to be called Al-Sayyid Bedouin Sign Language (ABSL), which originated approximately 75 years ago. There are two points relevant to our findings that are worth comparing with theirs. The first point pertains to whether an emerging sign language can have phonological structure. Since ABSL has neither minimal pairs nor the type of feature spreading rules (assimilation) commonly found cross-linguistically in spoken languages, Sandler and colleagues conclude it does not yet have phonology. They state, “ABSL might get along very well without dual patterning [phonology], and, we argue, it does” (Sandler et al. 2011). We are not proposing that finger complexity necessarily serve as a criterion to establish whether a particular language or a particular individual has or lacks a phonological system. We would agree that ultimately phonology must demonstrate systematic behavior, preferably of several kinds—including minimal pairs and phonological rules in the vocabulary of the language that are shared across a language community, but also including patterns such as the ones described here. We interpret the emergence of systematic patterns in finger complexity as one of the first indications of phonological organization. Our findings accord well with Ladd’s (2014) recent argument that phonology can be present without duality of patterning; we argue as well that duality of patterning not be an acid test for a phonological system. Instead, Handling and Object classes of handshape exhibit related organization at the phonological and morphological levels demonstrating the beginnings of both components of the grammar. Having the phonological pattern for selected fingers and joints facilitates the ascription of forms to their morphological classes. Starting with the more familiar and lower complexity forms, initial patterns of differentiation sets the ecology for categorizing the more complex and later acquired or later emerging forms. The redistribution of features across the two types of handshapes is phonology at work.

The second point is that Sandler, et al. (2011) argued that morphology precedes phonology in ABSL because duality of patterning is not (yet) in evidence, while ABSL already shows a pattern of morphological verb agreement using spatial devices (Sandler, et al. 2005). Sandler et al. arrived at their conclusions by looking at two very different phenomena—verb agreement on the one hand, which involves movement and location, and the form of lexical items, which involves handshape. We suggest that the work presented here is a better test case of the order of componential acquisition because it addresses two handshape phenomena that are closely related. Accordingly, our findings align more closely with those found for spoken language (MacWhinney, 1978, Ravid & Schiff, 2009); namely that phonology precedes morphology.

5.2. Language Variation

We found interesting crosslinguistic differences among the four sign languages in adults that are worthy of further investigation. In terms of their finger group complexity, LIS and NSL appear to exhibit similar patterns, and ASL and CSL appear to exhibit similar patterns, across multiple dimensions, despite the fact that this grouping pairs historically unrelated sign language together. In future work we will explore the typological variation among these languages, following on Padden’s division of sign languages into Object-preference and Handling-preference languages (Padden, Meir, Lepic, Hwang, Sampson & Seegers, 2013).

5.3 Language Acquisition and Emergence

Our examination of variation in finger complexity across handshape types in sign languages provides a window into the nature of the emergence of phonological systems. While it is clear that sign languages, even emerging ones, are not simply elaborated gesture systems that arise merely from use (Carrigan & Coppola, 2015), the gestural roots of the phonological contrast we discuss here start with the iconic influences that underlie "hand-as-hand" and "hand-as-object" representations. We find that the determinants of the initial forms of signs differ from the forces that reshape and reorganize a system of signs over time. Consequently, the organizational principles of sign languages grow to be qualitatively different from those of gesture. Sign languages do not merely echo or exaggerate the patterns present in gesture systems.

Language learners are key to this process of reorganization. In order to learn language, children must be able to identify the basic elements within a complex structure. This analytical eye, focused on an arbitrary arrangement, can detect seams where previously there were none. Thus learners create new elements as they learn. In the process of acquisition and emergence, signers (starting in childhood) become sensitive to a distinction between Object and Handling handshapes, and they begin to apply patterns of finger complexity that differentiate the two handshape types in a particular way. None of the gesture groups from which the signs apparently originate show this division of labor between the two handshape types. Yet they were evident already in a very young sign language, and in the signing of some young children who, in the meaning of their utterances, may not yet even mark the same contrast consistently. As more distinctions arise, new mappings can be realized, paving the way for more complex patterns to appear. And as each new generation learns the language, a phonology emerges.

Acknowledgments

This research has been supported in part by NSF BCS-0547554 and BCS-1227908 (to D.B. and M.C.) and NIH NIDCD R01-DC005407 (to A.S.), and by the Neubauer Collegium for Culture and Society at the University of Chicago. We also wish to thank Harry van der Hulst and three anonymous reviewers for their very helpful comments on earlier versions of this article. We are also grateful to the participants and their families, and to the team of research assistants and collaborators who worked on data collection and annotation, particularly Virginia Volterra and Alessio Di Renzo for the Italian data, and Yang Feng for the Chinese data.

References

Baayen, R. Harald, Douglas J. Davidson, & Douglas Bates. 2008. Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language* 594. 390–412. doi:10.1016/j.jml.2007.12.005

Barr, Dale, Roger Levy, Christoph Scheepers & Harry Tily. 2013. Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language* 68.255–278.

Bates, Douglas, Martin Maechler & Ben Bolker, B. 2014. lme4: Linear mixed-effects models using Eigen and S4. ArXiv e-print; submitted to *Journal of Statistical Software*, <URL: http://arxiv.org/abs/1406.5823>.

Benedicto, Elena & Diane Brentari. 2004. Where did all the arguments go? Argument-changing properties of classifiers in ASL. *Natural Language & Linguistic Theory* 22.1–68.

Benjamini, Yoav, & Yosi Hochberg. 1995. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society*, Series B. 57. 289-300.

Boyes Braem, Penny. 1981. *Distinctive Features of the Handshapes of American Sign Language.* Berkeley, CA. UC-Berkeley dissertation.

Boyes Braem, Penny. 1990. Acquisition of the handshape in American Sign Language: A preliminary analysis. In Virginia Volterra & Carol Erting (eds.) *From gesture to language in hearing and deaf children*, 107–127). New York: Springer.
Brentari, Diane. 1998. *A Prosodic Model of Sign Language Phonology*. Cambridge MA: MIT Press.
Brentari, Diane. 2010. *Sign Languages*. Cambridge, UK: Cambridge University Press.
Brentari, Diane. 2011a. Sign Language Phonology. In John Goldsmith, Jason Riggle, & Alan Yu (eds.) *Handbook of Phonological Theory*, 691-721. New York/Oxford: Blackwells.
Brentari, Diane. 2011b. Handshape in sign language phonology. In Marc van Oostendorp, Colin Ewen, Elizabeth Hume, & Keren Rice (eds.) *The Blackwell Companion to Phonology,* 195-222. New York: Blackwells.
Brentari, Diane. 2012. Sign language phonology: The word and sub-lexical structure. In Roland Pfau, Markus Steinbach, & Bencie Woll, (eds.) *Handbook of Sign Language Linguistics,* 21-54. Berlin: Mouton.
Brentari, Diane & Carol Padden. 2001. A language with multiple origins: Native and foreign vocabulary in American Sign Language. In Diane Brentari (ed.) *Foreign Vocabulary in Sign Language: A Cross-linguistic Investigation of Word Formation,* 87-119. Lawrence Erlbaum Associates, Mahwah, NJ.
Brentari, Diane & Petra Eccarius. 2010. Handshape contrast in sign languages. In Diane Brentari (ed.), *Sign Languages,* 284-311. Cambridge University Press.
Brentari, Diane, Marie Coppola, Laura Mazzoni & Susan Goldin-Meadow. 2012. When does a system become phonological? Handshape production in gesturers, signers, and homesigners. *Natural Language and Linguistic Theory,* 30(1).1-31.
Brentari, Diane, Marie Coppola, Ashley Jung & Susan Goldin-Meadow. 2013. Acquiring word class distinctions in American Sign Language: Evidence from handshape. *Language Learning and Development* 9(2).130-150. doi:10.1080/15475441.2012.679540
Brentari, Diane, Alessio Di Renzo, Jonathan Keane & Virginia Volterra. 2015. Cognitive, Cultural, and Linguistic Sources of a Handshape Distinction Expressing Agentivity. *TopiCS.* doi:10.1111/tops.12123
Carrigan, Emily & Marie Coppola. 2015, under review. Successful communication does not drive language development: Evidence from adult homesign.
Chen-Pichler, Deborah. 2012. Language acquisition. In Roland Pfau, Markus Steinbach, and Bencie Woll (eds.) *Handbook of sign Language Linguistics*, 647-684. Mouton de Gruyter: Berlin.
Conlin, Kimberly, Gene Mirus, Claude Mauk & Richard Meier. 2000. Acquisition of first signs: Place, handshape, and movement. In Charlene Chamberlain, Jill Morford & Rachel Mayberry (eds.) *Language Acquisition by Eye*, 51-69. Mahwah, NJ: Erlbaum.
Coppola, Marie & Diane Brentari. 2014. From iconic handshapes to grammatical contrasts: Longitudinal evidence from a child homesigner. *Frontiers in Psychology: Language Sciences*. doi:10.3389/fpsyg.2014.00830
Corazza, Serena. 1993. The history of sign language in Italian education of the Deaf. In Renate Fischer & Harlan Lane (eds.), *Looking Back. A Reader on the History of Deaf Communities and their Sign Languages,* 219–229. Hamburg, Germany: Signum Press.
Crasborn, Onno, & Han Sloetjes. 2008. Enhanced ELAN functionality for sign language corpora. In Onno Crasborn, Thomas Hanke, E. Efthimiou, Inge Zwitserlood & E. Thoutenhoofd (eds.), *Proceedings of LREC 2008*, 39–43. Paris: ELDA.
Dobrin, Lise. 1997. The morphosyntactic reality of phonological form. In Geert Booij and Jaap van Marle (eds.) *Yearbook of Morphology* 1997, 59–81. Dordrecht: Kluwer.
Eccarius, Petra. 2008. *A Constraint-based Account of Handshape Contrast in Sign Languages.* West Lafayette, IN. Purdue University PhD dissertation.
Eccarius, Petra & Diane Brentari. 2008. Handshape Coding Made Easier: A theoretically based notation for phonological transcription. *Sign Language and Linguistics 11(1).*69-101.
Ellenberger, Ruth & Marcia Steyaert. 1978. A child's representation of action in American Sign Language. In Patricia Siple (ed.) *Understanding Language Through Sign Language Research,* 261-

270. New York, NY: Academic Press.
Emmorey, Karen & Melissa Herzig. 2003. Categorical vs. gradient properties in classifier constructions in ASL. In Karen Emmorey (ed.) *Perspectives on Classifier Constructions in Sign Languages*, 221–246. Mahwah: Lawrence Erlbaum Associates.
Engberg-Pedersen, Elisabeth. 1993. *Space in Danish Sign Language*. Hamburg: Signum Verlag.
Fischer, Susan. & Qunhu Gong. 2010. Variation in East Asian Sign Languages. In Diane Brentari (ed.) *Sign Languages*, 499-518. Cambridge, MA: Cambridge University Press.
Fish, Sarah, Bruce Morén, Robert Hoffmeister, & Brenda Schick. 2003. The acquisition of classifier phonology in ASL by deaf children. In Vol. 1 of *Proceedings of the 27th Annual Boston University Conference on the Development of Language*, 252–263. Somerville: Cascadilla Press.
Fortune, Reo F. 1942. Arapesh. Publications of the American Ethnological Society, no. 19. New York: J. Augustin.
Geraci, Carlo, Valentina Aristodemo, Marie Coppola, Jordan Fenlon, & Diane Brentari. 2015. Cross-linguistic markedness of sign language handshapes. Ms. Institut Jean Nicod, École normale supérieure, Paris.
Goldin-Meadow, Susan, David McNeill & Jenny Singleton. 1996. Silence is liberating: Removing the handcuffs on grammatical expression in the manual modality. *Psychological Review* 103.34–55.
Goldin-Meadow, Susan, Diane Brentari, Marie. Coppola, Laura Horton & Ann Senghas. 2015. Watching language grow in the manual modality: Nominals, predicates, and handshapes. *Cognition.* doi.org/10.1016/j.cognition.2014.11.029
Halekoh, Ulrich, & Søren Højsgaard. 2014. A Kenward-Roger approximation and parametric bootstrap methods for tests in linear mixed models: The R package pbkrtest. *Journal of Statistical Software*, 59(9). 1-30.
Hara, Daisuke. 2003. *A complexity-based approach to the syllable formation in sign language*. Chicago, IL. University of Chicago PhD dissertation.
Hinton, Leeann, Johanna Nichols & John Ohala. 1994. *Sound Symbolism*. New York: Cambridge University Press.
Janis, Wynne. 1992. Morphosyntax of the ASL verb phrase. Buffalo, NY. State University of New York PhD dissertation.
Kantor, Rebecca. 1980. The acquisition of classifiers in American Sign Language. *Sign Language Studies 28*. 193-208.
Kegl, Judy. 1990. Predicate Argument Structure and Verb-Class Organization in the ASL Lexicon, in Ceil Lucas (ed.), *Sign Language Research: Theoretical Issues,* 149-175. Washington, DC: Gallaudet University Press.
Kegl, Judy & Gayle Iwata. 1989. Lenguaje de Signos Nicaragüense: A pidgin sheds light on the "creole?" ASL. In Robert Carlsson, Scott DeLancey, Spike Gildea, Doris Payne, and Anju Saxena (eds.) *Fourth Annual Meeting of the Pacific Linguistics Conference*, 266-294. Eugene, Oregon.
Kendon, Adam. 2004. *Gesture: Visible Action as Utterance*. Cambridge: Cambridge University Press.
Klima, Edward & Ursula Bellugi. 1979. *The Signs of Language*. Cambridge, MA: Harvard University Press.
Ladd, Robert. 2014. *Simultaneous Structure in Phonology*. Cambridge, UK: Cambridge University Press.
Lane, Harlan. 1984. *When the Mind Hears*. New York: Random House.
Lillo-Martin, Diane. 1999. Modality effects and modularity in language acquisition: The acquisition of American Sign Language. In William C Ritchie & Tej K. Bhatia (eds.) *Handbook of Language Acquisition*, 531-567. San Diego, CA: Academic Press.
Lillo-Martin, Diane. 2009. Sign language acquisition studies. In Edith Bavin (Ed.) *The Cambridge Handbook of Child Language*, 399-415. Cambridge: Cambridge University Press.
MacWhinney, Brian. 1978. *The acquisition of morphophonology* (Vol. 43, Monographs for the Society for Research in Child Development). Oxford, UK: Blackwells.

Marentette, Paula & Rachel Mayberry. 2000. Principles for an emerging phonological system: a case study early American Sign Language acquisition. In C. Chamberlain, Jill Morford, & Rachel Mayberry (eds.) *Language Acquisition by Eye*, 71-90. Mahwah, NJ: Lawrence Erlbaum Associates.
Marentette, Paula & Elena Nicoladis. 2011. Preschoolers' interpretations of gesture: Label or action associate? *Cognition* 121.386–399.
McIntire, Marina. 1977. The acquisition of American Sign Language hand configurations. *Sign Language Studies* 6. 247-266.
Meier, Richard, Claude Mauk, Adrianne Cheek & Christopher Moreland. 2008. The Form of Children's Early Signs: Iconic or Motoric Determinants. *Language Learning and Development* 4(1).63–98.
Meir, Irit & Wendy Sandler. 2007. *A Language in Space: The Story of Israeli Sign Language*. NY: Lawrence Erlbaum Associates.
Morgan, Gary, Sarah Barrett-Jones & Helen Stoneham. 2007. The First Signs of Language: Phonological Development in British Sign Language. *Applied Psycholinguistics* 28.3–22.
Newport, Elissa, & Richard Meier. 1985. The acquisition of American Sign Language. In. Dan Slobin (ed.) *The Cross-linguistic Study of Language Acquisition, Volume 1*, 881-938. Hillsdale, NJ: Lawrence Erlbaum Associates.
Padden, Carol, Irit Meir, So-One Hwang, Ryan Lepic, Tory Sampson & Sharon Seegers. 2013. Patterned iconicity in sign language lexicons. *Gesture* 13(3).287–308.
Piaget, Jean. 1952. *The origins of intelligence in children.* New York: International University Press.
Polich, Laura. 2005. *The Emergence of the Deaf Community in Nicaragua*. Washington, DC: Gallaudet University Press.
Quer, Josep, Laura Mazzoni & Galini Sapountzaki. 2010. Transmission of sign languages in Mediterranean Europe. In Diane Brentari (ed.) *Sign Languages* (pp. 570 – 592). Cambridge, UK: Cambridge University Press.
Ravid, Dorit, & Rachel Schiff. 2009. Morphophonological categories of noun plurals in Hebrew. *Linguistics, 47*, 45-63.
R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.
Sandler, Wendy. 2011. The Phonology of Movement in Sign Language. In Marc van Oostendorp Colin Ewen, Elizabeth Hume, and Keren Rice (eds.) *The Blackwell Companion to Phonology*, 577-603. Oxford: Blackwell Publishing Ltd. <http://www.companiontophonology.com>
Sandler, Wendy. 2012. Visual prosody. In Roland Pfau, Markus Steinbach, & Bencie Woll, eds., *Handbook of Sign Language Linguistics*. Berlin: Mouton.
Sandler, Wendy, Mark Aronoff, Irit Meir & Carol Padden. 2011. The gradual emergence of phonological form in a new language. *Natural Language & Linguistic Theory 29*.503–543.
Sankoff, Gillian & Suzanne Laberge. 1973. On the acquisition of native speakers by a language. *Kivung*, 6, 32-47.
Schembri, Adam, Caroline Jones & Denis Burnham. 2005. Comparing action gestures, and classifier verbs of motion: Evidence from Australian Sign Language, Taiwan Sign Language, and nonsigners' gestures without speech. *Journal of Deaf Studies and Deaf Education 10*. 272–290.
Schick, Brenda. 1987. *The Acquisition of classifier predicates in American Sign Language*. West Lafayette, IN: Purdue University PhD dissertation.
Senghas, Ann. 1995. *Children's Contribution to the Birth of Nicaraguan Sign Language.* Cambridge, MA: Massachusetts Institute of Technology Ph.D. dissertation. [Distributed by MIT Working Papers in Linguistics, Cambridge, MA]
Senghas, Ann & Marie Coppola. 2001. Children creating language: How Nicaraguan Sign Language acquired a spatial grammar. *Psychological Science* 12(4). 323-328.
Senghas, Ann, Sotaro Kita, & Asli Özyürek. 2004. Children creating core properties of Language: Evidence from an emerging sign language in Nicaragua. *Science* 305.1779-1782.
Singleton, Jenny & Elissa Newport. 2004. When learners surpass their models: The acquisition of American Sign Language from inconsistent input. *Cognitive Psychology 49* (4).370-407.

Stokoe, William C. 1960. *Sign Language Structure: An outline of the visual communication systems of the American deaf (Occasional Papers 8)*. Buffalo, NY: University of Buffalo.
Supalla, T. 1982. *Structure and acquisition of verbs of motion and location in American Sign Language*, San Diego, CA: University of California PhD dissertation.
Tang, Gladys, Scholastica Lam, Felix Sze, Prudence Lau, & Jafi Lee. 2008. Acquiring verb agreement in HKSL: Optional or obligatory? In Ronice Müeller deQuadros (ed.) *Sign Languages: spinning and unraveling the past, present and* future, 613-638. Brazil: Editora Arara Azul.
van der Hulst, Harry. 1995. The composition of handshapes. *University of Trondheim Working Papers in Linguistics 23*.1–17.
Vihman, Marilyn. 1996. *Phonological Development. The Origins of Language in the Child*. Oxford, UK: Blackwell.
Volterra, Virgina. 1987. *La lingua italiana dei segni*. Bologna: Il Mulino. (2nd edition, 2004)