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Emergent Morphology in Child Homesign: Evidence from Number Language

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ABSTRACT

Human languages, signed and spoken, can be characterized by the structural patterns they use to associate communicative *forms* with *meanings*. One such pattern is paradigmatic morphology, where complex words are built from the systematic use *and re-use* of sub-lexical units. Here, we provide evidence of emergent paradigmatic morphology akin to number inflection in a communication system developed without input from a conventional language, *homesign*. We study the communication systems of four deaf child homesigners (mean age 8;02). Although these idiosyncratic systems vary from one another, we nevertheless find that all four children use handshape and movement devices productively to express cardinal and non-cardinal number information, and that their number expressions are consistent in both form and meaning. Our study shows, for the first time, that all four homesigners not only incorporate number devices into representational devices used as predicates , but also into gestures functioning as nominals, including deictic gestures. In other words, the homesigners express number by systematically combining *and re-combining* additive markers for number (*qua* inflectional morphemes) with representational and deictic gestures (*qua* bases). The creation of new, complex forms with predictable meanings across gesture types and linguistic functions constitutes evidence for an inflectional morphological *paradigm* in homesign and expands our understanding of the structural patterns of language that are, and are not, dependent on linguistic input.

Introduction

As humans, we are born "language ready." A child will absorb and produce whatever language(s) are available and accessible to them. But what about a child who has no accessible language available? That is the situation of deaf children born into non-signing families, who have no available sign language and for whom spoken language is inaccessible. Children in these situations develop idiosyncratic communication systems called *homesign* to communicate with the hearing individuals around them. Though they lack input from a conventional language, homesigners develop gesture systems that display *language-like* properties ranging from rudimentary phonology (Brentari et al., 2012) to systematic syntactic structures (Goldin-Meadow & Feldman, 1977) that are composed hierarchically (Hunsicker & Goldin-Meadow, 2012).[1] These systems provide unique insight into the biological

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[1]Homesign systems are not, however, fully developed languages. We support the right of all deaf children to have access to sign language and we encourage readers to do the same. In the United States, the *Language Acquisition and Education for Deaf Kids* (http://www.lead-k.org/) campaign is working nationwide to improve sign language access. In Nicaragua, *Signs and Smiles* (https://www.signsandsmiles.org/) works to improve language access as well as educational and vocational opportunities for deaf Nicaraguans.

Supplemental data for this article can be accessed on the publisher's website.

capacity for language. The properties present in homesign are innovated, not acquired, and these innovations may reflect innate structural capacities and biases that are brought to the task of language-learning. Here, we provide evidence from number language that child homesigners are able to innovate *paradigmatic* morphological structure akin to number inflection.

Our research builds on Coppola et al.'s (2013) study of the handshape and movement devices that homesigning adults and one homesigning child used to express cardinal and non-cardinal number information. In addition to replicating and extending Coppola et al.'s findings to three more children, our study documents new number phenomena, and in doing so we provide novel evidence for morphological structure in homesign. The children systematically incorporate their cardinal and non-cardinal number forms into gestures serving different grammatical functions (predicate, nominal) and having different meaning sources (representational, deictic). They thus seem to have innovated stable number "morphemes" that can be combined productively to create complex gestures with predictable, compositional meanings. Such systematicity in form and meaning provides evidence for a paradigmatic system in which complex gestures (*qua* words) can be analyzed as the discrete and recurrent combination of base lexemes with additive markers of number (*qua* inflectional morphemes). Moreover, as in conventional languages, the homesigners include these number-inflected forms as part of multi-gesture propositional utterances––that is, as part of the syntagmatic structure of their communication (section 3.3).[2] Before introducing our study, we first provide a brief overview of number language (1.1), including what is known about number expression in emergent homesign systems (1.2).

Number as a universal property of human language

Humans are but one of many species that have the capacity to perceive, conceptually represent, and reason about quantity (Brannon, 2005). Our cultural experience mediates the quantities we distinguish and the reasoning we engage in about these quantities (Núñez, 2011), but the basic drive to perceive a parceled-out world may be a cognitive primitive, as further affirmed by evidence that numerical perception is present in newborns (Izard et al., 2009). Quantity, it appears, is fundamental to how we understand the world. Likewise, linguistically encoding quantity information, which we refer to as *number* or *number language*, appears to be fundamental to how we talk about the world. The referents of quantity expressions in language may be entities or events, individuals or sets; building on the earlier intuitions of Locke (1847[1690]) and Frege (1884), Wiese (2003) proposes that potential countability is the only restriction imposed on the otherwise "enormous flexibility" of number language. Number emerges early in both production (Brown, 1973) and perception (Kouider et al., 2006) and we know of no language that is wholly without number,[3] although languages do vary in how number is expressed. Here, we briefly discuss patterns in how quantity information is expressed in conventional (signed and spoken) languages, focusing on the phenomena and patterns of variation that lay the groundwork for the present study.[4]

[2]The division of labor between morphology and syntax is difficult to pin down, and frameworks like Distributed Morphology (Halle & Marantz, 1993) posit that no such clear division exists. We remain neutral as to the computational engine(s) responsible for paradigmatic and syntagmatic structure. Moreover, our claim is that the homesigners' number language provides *evidence of* regular paradigmatic structure. Morphological irregularities and inconsistencies abound in conventionalized languages and are not incompatible with paradigmatic analysis (Corbett, 2007). Such irregularities are, however, more challenging to identify in homesign systems, though see section 4.4 for a discussion of constraints on the incorporation of numeral handshapes.

[3]A suggested counterexample is Pirahã, which has been claimed to lack words for exact quantities and grammaticalizes no distinction in morphological number (Everett, 2005). However, Gordon (2004) and Frank et al. (2008) show that this language has linguistic expressions for relative or approximate number.

[4]A more comprehensive overview of grammatical number is provided by Corbett (2000); for an accessible introduction to quantity cognition, see Dehaene (1997).

Cardinal and non-cardinal quantity information can be expressed lexically and morphologically

Cardinal number language expresses information about exact count. Lexical numerals like *twelve* are prototypical examples of cardinal number language but so are items like *dozen* and *twice*, with the latter illustrating that quantification may be about events as well as entities. Language can also express inexact or non-cardinal quantity, as with lexical items like *many* and *often*. For both cardinal and non-cardinal quantity, there are also morphological strategies for expressing number. Plural markers like *-s* in English (*boy* vs. *boys*) express number non-cardinally, but cardinal number can be morphologically expressed with more specific inflections such as dual.

These distinctions are modality-independent. Abner and Wilbur (2017) and Kimmelman (2017) document an array of morphological and lexical strategies for expressing cardinal and non-cardinal quantity in American Sign Language (ASL) and Russian Sign Language (RSL), respectively. Cardinal numeral expressions have also been documented and explored in the lexicons of sign languages that have emerged in relatively isolated communities with high rates of hereditary deafness (Zeshan et al., 2013). Many sign languages also code cardinality using the morphological process of "numeral incorporation," in which a base lexical item (e.g., HOUR) and a cardinal number handshape (e.g., TWO) are combined into a single sign: TWO-HOUR.[5] Reduplication has also been observed to encode number morphologically in sign languages, and can do so on both nouns and verbs (Supalla & Newport, 1978). Form differences in reduplication have been observed to track cardinal and non-cardinal meaning distinctions (Padden, 1988; see Steinbach, 2012 for a recent overview).

Cardinal and non-cardinal number on deictic forms

Number can also be expressed with deictics, such as personal pronouns.[6] Here, too, we find lexical and morphological expressions for number. For example, number is distinguished lexically in English first person pronouns (e.g., *I* vs. *we*). In Tok Pisin, however, first person inclusive *yumi* may be morphologically derived from the second person *yu* and the first person singular *mi*. In ASL, I points at the signer's chest a single time and WE does so twice (see Cormier, 2002, for detailed discussion). The doubling in WE is not cardinally significant (i.e., it means more than one, not necessarily "two"), but the distinction between cardinal and non-cardinal number is relevant for deictics. Abner (2012) observes that reduplicative markers like those used with nouns and verbs can also be combined with deictics in ASL and that deictic reduplication can yield both cardinal (dual) and non-cardinal (collective or distributive plurality) meaning. Cross-category morphological similarities, which we return to below, are also attested in numeral incorporation: deictics can incorporate numeral handshapes to form signs like THREE-OF-US in ASL.

Number as part of the syntactic system

In addition to its lexical and morphological manifestations, number is also relevant for the broader syntagmatics of language. For example, in colloquial Russian, syntactic inversion of a numeral and noun can be used to shift to an approximate (i.e., non-cardinal) number meaning (Yadroff & Billings, 1998). With respect to sentence structure, number may be expressed on arguments or predicates or both, as is the case when verbal inflection reflects agreement with the number of the subject (e.g., *he/she/it walks* vs. *they walk*). Multiple marking of number may also occur within a constituent, as in FIVE BOOK++ (*five books*) in Italian Sign Language (Pizzuto & Corazza, 1996). This process is usually termed *concord* rather than agreement. In both agreement and concord, language-specific patterns and restrictions are common. For example, reduplicated plurals like BOOK++ are grammatical by themselves in German Sign Language, but the phrase *FIVE BOOK++ is ungrammatical (Steinbach, 2012). The individual number expressions in a multiply-marked structure can convey different information (e.g.,

[5]Following convention, we use SMALL CAPS English translations to represent the meaning of signs (HOUR, TWO). If multiple English words are necessary to represent the meaning of an individual sign, these words are connected with hyphens (TWO-HOUR). We also follow these conventions for the homesigners' representational gestures.

[6]The connection between number and deixis may be especially salient in Chadic languages, where there are synchronic and diachronic connections between demonstratives and plural markers (Frajzyngier, 1997).

BOOK++ is non-cardinal but FIVE is cardinal) or can be numerically redundant (e.g., *they* and *walk* are both non-cardinal). We next examine homesign systems and show that number can be innovated by linguistically isolated individuals.

Number in homesign

Homesigns are the gestural systems created by profoundly deaf individuals to communicate with the (usually hearing) people around them (Goldin-Meadow, 2003). Because they cannot access ambient spoken language and have not been exposed to a sign language, homesigners have no conventional language input. They also lack a conventional language community, as their communication partners are not themselves *producers* of the homesign system (Flaherty et al., 2021; Goldin-Meadow & Mylander, 1983, 1984, 1998) and perform poorly as *comprehenders* of the system (Carrigan & Coppola, 2017). Thus, homesign systems are not borne of typical language exposure and experience. Nevertheless, homesign systems do show certain hallmarks of linguistic structure. They exhibit systematic word order patterns (Goldin-Meadow & Feldman, 1977), hierarchical organization (Hunsicker & Goldin-Meadow, 2012), lexical category distinctions such as noun, verb, and adjective (Abner et al., 2019; Goldin-Meadow et al., 1994), hand and motion morphemes that combine to form stems (Goldin-Meadow et al., 1995, 2007), and the groundwork of phonology (Brentari et al., 2012).

With respect to number, Coppola et al. (2013; see also Spaepen et al., 2011, 2013) studied the productions of four adult homesigners in Nicaragua and found that they used three devices for expressing number information: Finger Extension (FE) handshapes, Punctuated Movement (PM), and Unpunctuated Movement (UM). The homesigners used FEs to express number as stand-alone gestures, akin to lexical cardinal numerals (e.g., THREE; we call these "Isolated FEs"). They also used FEs as handshapes incorporated into other gestures (e.g., a FALL gesture produced with a 3-handshape: 3HS-FALL), akin to numeral incorporation. With PMs and UMs, reduplication-like repetition of a gesture's movement is used to indicate information about number (e.g., a FALL gesture with repeated movements). Such movement repetition could involve either discrete, punctuated movements (PMs, FALL$_{\text{PM}=3}$) or non-discrete, continuous movements (UMs, FALL$_{\text{UM}=3}$). The distinction between these three devices (FEs, PMs, UMs) was established on the basis of formational criteria alone. However, Coppola et al. (2013) found that these formational distinctions also differed in their number meaning. FEs and PMs were found to track exact quantity and thus seemed to express cardinal number. In contrast, UMs did not track exact quantity and instead seemed to express number information non-cardinally. Coppola et al. (2013) also probed how these number devices emerge by studying the gestures of the homesigners' communication partners (see 4.1 for more discussion), as well as the gestures of one deaf homesigning child. The child in their study produced forms (FEs, PMs, UMs) similar to the adults and, moreover, differentially associated these forms with cardinal (FEs, PMs) and non-cardinal (UMs) meanings.

In the present study, we dig deeper into the expression of "Number" in homesign systems by first replicating Coppola et al.'s findings in three additional homesigning children. We ask if the three children (plus the fourth studied by Coppola et al.) produce these number forms and if they use them to distinguish cardinal and non-cardinal meaning. But our primary contribution is to expand the linguistic scope of the study beyond Coppola et al. (2013), who looked only at number-marking devices incorporated into representational predicative gestures. We also look at number-marking devices incorporated into nominal gestures, both representational nominal gestures and deictic nominal gestures. We ask whether these number devices appear with different gesture types. If we find that number-marking devices are incorporated into distinct gesture types that serve multiple grammatical functions, we will have evidence for a productive morphological system for expressing number, one with a *paradigmatic* structure that exhibits the kind of cross-categorial similarity often observed in the number morphology of conventionalized sign languages.

Methods

Participants

Four deaf child homesigners (one female-presenting) living in Nicaragua participated in the study; one child (CHS1) was previously studied by Coppola et al. (2013). The children participated willingly in the study activities and informed consent was obtained from the children's guardians. Little research exists on the development of numerosity and number language in children acquiring sign language. However, Secada (1984) and Leybaert and Van Cutsem (2002) showed that deaf signing children exhibit similar counting abilities as same-age hearing peers (albeit with lags in some measures and some differences in error types). The participants in our study range in age from 7 years and 3 months to 9 years and 10 months (average age 8 years 2 months; see Table 1 for ages of each participant). Only one child (CHS4, 7;03) is in the age range studied by Secada (3;6–7;6) and the remaining three are all older than those studied by either Secada or Leybaert and Van Cutsem (4–6;2). Based on their results, the quantities in our vignettes (see 2.2 and supplemental materials Table S1) would be within the expected counting abilities of a deaf signing child as young as our youngest participant. Moreover, all four children are chronologically well beyond the age at which number cognition and number language emerge in typically developing hearing children learning spoken language (cf. Wynn, 1990, 1992). Based on experimenter observation and family reports, as well as audiogram results for the one child on whom we had this type of data (CHS1), all four children were profoundly deaf and without other diagnosed cognitive impairments. None of the children had acquired any usable spoken language (the children's families were all Spanish-speaking). The children did not interact with one another and none of them regularly interacted with any other deaf individuals. One child (CHS2) did have two deaf extended family members who do not use Nicaraguan Sign Language and who have limited-to-no contact with the child. Thus, the children have not been exposed to any conventionalized sign language (as is common for deaf individuals in Nicaragua), nor are they members of an emergent homesign micro-community. Any number expressions they produced are therefore likely to be part of their self-created homesign system. The children also did not have any mathematical schooling; there is a school for deaf children in the capital city of Managua, but none of the children lived there (CHS4 did attend school, albeit in a regular education classroom for hearing students so the educational materials were largely inaccessible).

Table 1. Distribution of the number gestures across child homesigners (CHS). Individual homesigners are listed with their age (years; months). Counts of number devices incorporated into representational and deictic gestures (Figure 1) are displayed in the first six rows. FEs are Finger Extensions, PMs are Punctuated Movement repetitions, and UMs are Unpunctuated Movement repetitions. Devices that stand on their own (Figure 2) are displayed in the bottom of the table ("Non-Incorporated Number Devices"). The penultimate column lists the total instances across children of each number device type combination and the penultimate row lists the total instances of number devices per child. The final column and row identify how many children produced each combination (final column) and how many of the combinatoric types each child produced (final row).

Number Gesture Form			Number Gesture Use Across Homesigners (age)					
			CHS1 (8;03)	CHS2 (9;10)	CHS3 (7;04)	CHS4 (7;03)	Total	Number of Homesigners Producing Each Device (out of 4)
Incorporated Number Devices	Representational	FE	2	0	6	0	8	2/4
		PM	4	7	13	2	26	4/4
		UM	4	6	3	0	13	3/4
	Deictic	FE	2	0	1	9	12	3/4
		PM	14	8	43	21	86	4/4
		UM	1	0	10	1	12	3/4
Non-Incorporated Number Devices	Isolated FE		110	15	43	54	222	4/4
	Group Point		0	10	24	0	34	2/4
	Group Sweep		2	4	66	3	75	4/4
Total Number Device Gestures Produced by Each Child			139	50	209	90	488	
Number Device Combination Types Used by Each Child (out of 9)			8/9	6/9	9/9	6/9		

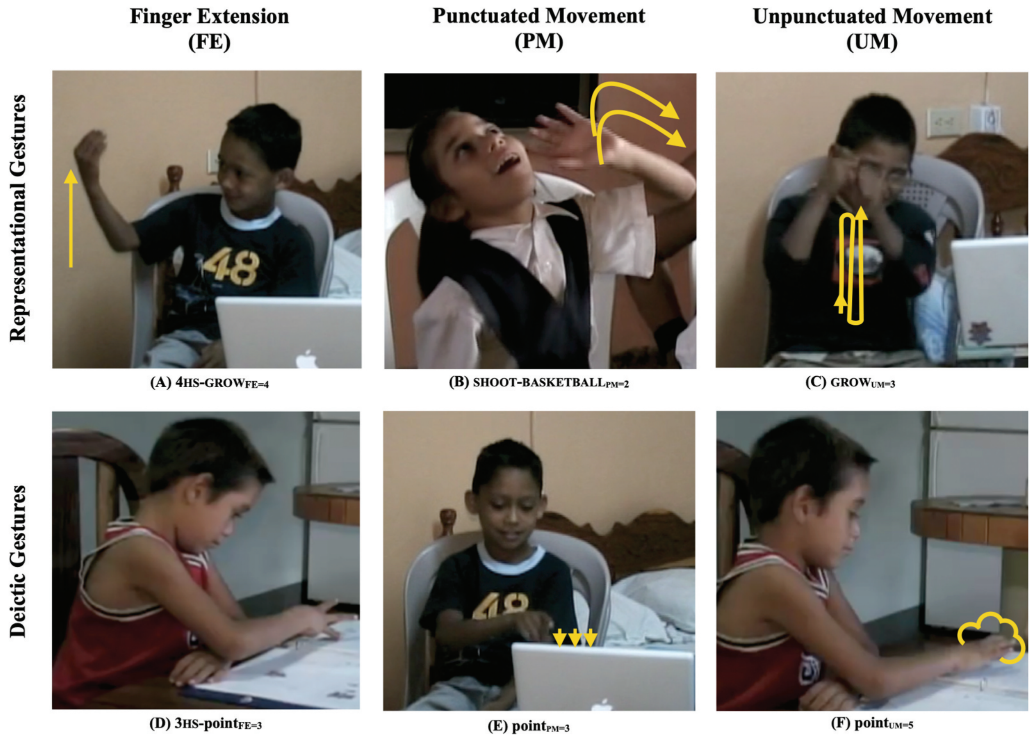

Figure 1. Incorporated number devices in which Finger Extensions (FEs, 1st column), Punctuated Movements (PMs, 2nd column), or Unpunctuated Movements (UMs, 3rd column) were incorporated into representational (top row) or deictic (bottom row) gestures. In (A), the homesigner incorporates a 4 FE into a GROW representational gesture to describe flowers growing out of four boxes. In (D), the homesigner incorporates a 3 FE into a deictic gesture to indicate three uneaten ice cream cones. In (B), the homesigner incorporates 2 PMs into a SHOOT representational gesture to describe two men shooting basketballs. In (E), the homesigner incorporates 3 PMs into a deictic gesture to indicate three flowers growing out of three boxes. In (C), the homesigner incorporates 3 continuous up-and-down UMs into a GROW representational gesture to describe many flowers growing out of boxes. In (F), the homesigner incorporates 5 UMs into a deictic gesture to indicate many straws in a cup.

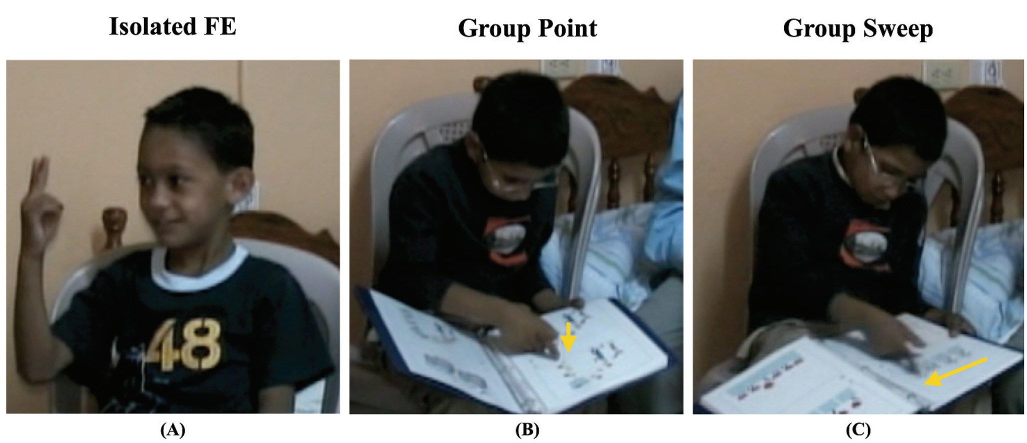

Figure 2. Non-incorporated number devices (Isolated FE, Group Point, Group Sweep). In (A), the homesigner extends two fingers to indicate two red cups falling over (Isolated FE). In (B), the homesigner produces a deictic gesture at the group of basketballs in a picture (Group Point). In (C), the homesigner sweeps a deictic gesture under a picture of five bananas sitting on boxes (Group Sweep).

Materials and procedures

Participants were videotaped describing one of two sets of ten brief vignettes (Set A, Set B) that featured varying numbers of objects and events (see supplemental material Table A1 for vignette descriptions). The two sets differed only in number. For example, in the fifth vignette of Set A, five cups are in a row on a table and fill one at a time with solid color (three orange, two red). After the cups have filled, two orange cups fall over at one a time. In the Set B version of this vignette, there are six cups total, all six fill (five orange, one red), and three fall over (again, all orange). The vignettes were the same as those used to elicit number language by Coppola et al. (2013).

Each child viewed the vignettes on a laptop computer in the presence of a communication partner, as well as an experimenter conducting the task. For two of the children (CHS1, CHS2), the communication partner was the child's mother. The communication partner for the remaining two children was a second experimenter. Homesigners were familiar with both experimenters and frequently directed their communicative gestures toward them or other individuals present. We observed no noticeable differences in participants' communication or completion of the task related to the communication partners present. Before viewing the vignettes, the homesigners were told (in gesture) to watch what was taking place on the screen and describe what they saw. Sometimes the children were also encouraged to elaborate their descriptions. For example, communication partners might use a general interrogative palm-up gesture to ask for more information, or they might indicate the objects and encourage the homesigner to count by brushing the thumb along the tips of the fingers of the same hand, a conventional gesture in Nicaragua (an *emblem*; Ekman & Friesen, 1969). When combined with a scrunched nose (a conventional non-manual questioning gesture in Nicaragua), this is a nonverbal way of asking *how many*. The hearing communication partners––both experimenters and the children's mothers––also occasionally produced spoken or mouthed Spanish question words like *cuántos* ("How many?") or *que* ("What?"), sometimes accompanied by interrogative gestures. Homesigners did not receive any feedback on numerical accuracy.

Our aim was to collect a rich body of communication about quantity from each of the homesigners (and we briefly touch on non-elicited number language in 4.1). Homesigners sometimes viewed vignettes multiple times while describing them. We also created a book of static images to encourage conversation about the vignettes (Figure S1 in the supplemental materials provides a sample set of images from the book). One child (CHS3) looked through and described the static images before viewing the vignettes; the gestural descriptions produced during this activity were coded and included in the analyzed data (Table S2 in the supplemental material provides detailed trial information). The communication partners and experimenters sometimes used the images to help encourage elaborations (e.g., by pointing to a picture and producing an interrogative gesture). Descriptions of the number vignettes were all elicited during the same fieldtrip to Nicaragua in 2007, but were usually separated by other elicitation tasks and sometimes occurred on separate days.

Coding

The homesigners produced 2508 gestures (761 CHS1, 408 CHS2, 1041 CHS3, 298 CHS4) in response to the vignettes (supplemental material Table S3 provides additional details on counts of gestures and utterance units produced). These gestures were transcribed and coded using the system developed by Goldin-Meadow and Mylander (1984), supplemented with coding for number language, described below. Individual gestures were coded for the referential meaning of the gesture. The link between form and meaning can be established in one of three ways: via convention, via iconicity, and via deixis. *Convention*: The homesigner uses emblems that have an established form and meaning in the ambient community; for example, the Nicaraguan gesture for *counting* described earlier.[7] *Iconicity*: The homesigner uses a gesture that non-arbitrarily captures an aspect of the intended referent; for example, an ELEPHANT gesture produced by moving the hand out from the head so as to visually depict an elephant's trunk. For the purposes of the present discussion, we refer to both conventional and iconic gestures using the umbrella term "representational gestures" (Isolated FEs, described below, are treated as a separate category). *Deixis*: The homesigner uses pointing to establish meaning; for example, a homesigner may point to a woman in the room to refer to that woman, another woman, or women in general (see Butcher et al., 1991; Goldin-Meadow et al., 2005).

Imitations of gestures produced by a communication partner (67 total; 6 CHS1, 21 CHS2, 29 CHS3, 11 CHS4), aborted or interrupted gestures (20 total; 5 CHS1, 1 CHS2, 12 CHS3, 2 CHS4), traces of Arabic numerals (1 CHS1), or gestures for which the communicative intent was unclear (229 total; 23 CHS1, 75 CHS2, 105 CHS3, 26 CHS4) were excluded from the analysis. After these exclusions, 2189 gestures (726 CHS1, 309 CHS2, 895 CHS3, 259 CHS4) remained. Inter-coder reliability was established by having three vignettes from each child coded by a second coder. The second coder was trained in homesign coding and was familiar with the stimuli and aware that the study was about number, but was blind to the specific distinctions being investigated. Inter-coder agreement was 89% for identifying gestures and 85% for assigning gesture meaning.

We adopted Coppola et al.'s (2013) form-based classification for the three types of number gestures described above:

(i) *Finger Extensions (FEs)*: The homesigner extends their fingers to represent quantity. As discussed further in 3.1, we observed FEs incorporated into both representational gestures (Figure 1A) and deictic gestures (Figure 1D). The children also frequently produced FEs in isolation, as in Figure 2A.

(ii) *Repeated Punctuated Movements (PMs)*: The homesigner repeats the movement in the gesture to code number, and does so using discrete, easily segmented movements. Figure 1B depicts a PM incorporated into a representational gesture (two punctuated arc-shaped shooting movements describing two men shooting basketballs); Figure 1E depicts a PM incorporated into a deictic gesture (three punctuated pointing movements at the laptop screen where flowers grew).

(iii) *Repeated Unpunctuated Movement (UMs)*: As in PMs, movement repetition again appears to be used to express information about number, but the repetitions are a series of quick, iterated movements with no clear breaks between them. Figure 1C depicts a UM incorporated into a representational gesture (three quick up-and-down unpunctuated movements describing flowers growing in boxes); Figure 1F depicts a UM incorporated into a deictic gesture (five quick unpunctuated pointing movements produced in a circle pointing to a cup with five straws).

Unlike FEs, PMs and UMs are always incorporated into other gestures (movement cannot occur in isolation). We also coded two additional deictic forms that the homesigners used to communicate about sets: Group Points and Group Sweeps (Figure 2B,C). The Group Point is a deictic gesture that points to a group of objects, rather than to a single object. Group Points are often directed at a location at the edge of a collection of objects; see Figure 2B, where the child points to the empty space below a line of basketballs. Group Sweeps also refer to groups of objects, but do so with a sweeping motion; see Figure 2C, where the child sweeps his finger across a row of bananas. Both Group Points and Group Sweeps can be, and were, repeated. Repetition of Group Points tends to yield a tapping motion, and repetition of Group Sweeps a back-and-forth movement.

[7]Gestures of the ambient hearing community frequently serve as a source for signs in conventionalized sign languages and homesign. When these gestures are adopted into these communicative systems, however, signers (Frishberg, 1975; Janzen & Shaffer, 2002) and homesigners (Franklin et al., 2011) may systematize or extend their meaning or function.

With the addition of Group Points and Group Sweeps, there were nine possible number-marking combinations. Inter-coder agreement was 90% for identifying gestures expressing number and 91% for classifying number gestures.

Whenever number devices were identified, they were assigned a Gesture Value based on the number of fingers extended (FEs) or the number of movement repetitions produced (PMs, UMs). Gesture Value was assigned to FEs independent of which fingers were extended. For example, an extended thumb and index finger handshape would receive the same Gesture Value ("2") as an extended index and middle finger handshape. Inter-coder agreement for Gesture Value was 94%.

All number gestures were also assigned a Target Value representing the number of objects or events that the gesture was about. By design, the vignettes contained an array of distinct quantities, and context was used to determine the quantity target for a given gesture. For example, when a child pointed with a 2-handshape to the empty lily pads in Vignette 6, we assigned a Target Value of "2" to match the number of empty lily pads, rather than "12" for the total number of lily pads or "10" for the number of lily pads with frogs on them. Inter-coder agreement for assigning Target Value was 86%.

We also coded utterance-level properties. Following Goldin-Meadow and Mylander (1984), utterance breaks were identified using manual and non-manual cues, such as a relaxation of the hands, an extended pause, or breaks occurring in turn-taking. Inter-coder agreement for identifying utterance breaks was 83%. Each gesture was also classified according to its grammatical function within the utterance. Representational and deictic gestures referring to entities were coded as serving a nominal function, and representational gestures referring to relations or attributes were coded as serving a predicate function. Inter-coder agreement for grammatical function was 96%. We also assigned semantic roles to nominals (e.g., actor, entity, patient) and predicates (e.g., act, attribute, be-located) and coded the order of elements in multi-gesture utterances. Inter-coder agreement was 96% for classifying predicates, 93% for classifying nominal arguments, and 91% for coding order of elements. Finally, each proposition was classified according to whether and how number marking was incorporated (e.g., on an argument or predicate; see Section 3.3.1, Table 3, for details). Inter-coder agreement for this utterance type classification was 95%. These procedures allowed us to examine not only *if* the children expressed number information, but also *how* number information was expressed at the gesture and utterance levels.

Results

To investigate whether or not number-marking is part of an emergent morphological system in homesign, we first examine the distribution of number devices across gesture types (3.1). We then look at whether or not the homesigners' number forms exhibit consistent form-meaning pairings with respect to the quantity information they express (3.2). Finally, we assess whether and how these gesture-level morphological devices are incorporated into the homesigners' emergent syntactic systems (3.3).

Number gesture forms across gesture types

The four children in our study each use a self-created homesign system. These systems varied from one another, as would be expected given the idiosyncratic nature of homesign and the fact that individual differences are a natural part of language. For example, as with users of conventionalized languages, some of the homesigners simply communicated more than others. Situational factors also affected the amount of data from each child. For example, CHS3 was loquacious and enjoyed the activity, whereas CHS4 was more reserved and was easily distracted by the other children present in the only testing site available. Nevertheless, all four children used FEs, PMs, and UMs to express number information in response to the vignette activity (see 4.1 for a brief description of number devices in spontaneous communication). Importantly, our claim is one of capacity, not frequency.[8] This shared capacity for number cannot be attributed to a shared communication system, as the homesigners did not know one another.

Importantly, in addition to number-marking predicate gestures (documented by Coppola et al.), we also found FEs, PMs, and UMs incorporated into representational and deictic gestures referring to objects, and thus serving a *nominal* or *argument* role.[9] All four homesigners incorporated PMs into their deictic gestures, and three incorporated UMs and FEs into their deictic gestures. Moreover, all four homesigners produced at least one of the incorporated device types (FE, PM, or UM) with *both* a representational and deictic gesture (and two of the four produced all three devices with both types of gestures). In other words, these number forms seem to be behaving as discrete units that can be combined with the "lexemes" (representational and deictic gestures) of the homesign system. Table 1 presents the frequency of FEs, PMs, and UMs incorporated into representational and deictic gestures, as well as the non-incorporated number devices that the homesigners produced. All four homesigners produced Isolated FEs and Group Sweeps, and two produced Group Points. We turn next to the number meanings expressed by the forms listed in Table 1.

Relationship between gesture form and number meaning

The homesigners in our study produce FE, PM, and UM *forms* with predicate and nominal gestures. But do the homesigners associate these forms with consistent *meanings*, as would be expected in a morphological system? Specifically, do the homesigners' number-marked gestures differentially express cardinal (FE, PM) and non-cardinal (UM) number? To answer this question, we assessed Gesture Value relative to the actual quantity to which the gestures referred (Target Value). We evaluated how closely Gesture Value *tracked* Target Value (3.2.1), as well as overall accuracy of Gesture Value (3.2.2). Because the meaning of Group Sweeps and Group Points could either be singular (e.g., *the group*) or plural (e.g., *these objects*), we leave these gestures out of our initial assessments of cardinality, but we briefly consider them in 3.2.3

Quantity tracking of number gesture forms

If a gesture is expressing cardinal number, then we expect Gesture Value to increase systematically as Target Value increases. In Figure 3, we depict the number tracking patterns of the homesigners' FE, PM, and UM devices, collapsed across gesture type (representational and deictic gestures) and compared to a perfectly cardinal system (see Figure S2 in the supplemental material for representational and deictic gestures depicted separately).

The homesigners' FEs and PMs exhibit behavior consistent with a cardinal system. The Gesture Value of these devices systematically increase as Target Value increases ($r = .96$ for FEs, .97 for PMs). UMs, in contrast, behave differently ($r = .71$). To assess the relative strengths of these correlations, we used Dunn and Clark's modification of the Fisher z-test for comparing dependent overlapping correlations using the *cocor* package (Diedenhofen & Musch, 2015) in R statistics (R Core Team, 2020). FEs and PMs did not significantly differ from each other ($z = 0.5658$, $p = .5716$), but UMs differed significantly from both FEs ($z = 2.2437$, $p = .0249$) and PMs ($z = 3.1248$, $p = .0018$). Not surprisingly, when FEs and PMs are collapsed, there is also a significant difference between these cardinal devices and UMs ($z = -2.7974$, $p = .0052$). Because this analysis must exclude Target Values that are not represented in *both* of the to-be-compared items, there was not enough data to statistically compare number tracking patterns in representational versus deictic gestures, but UMs do display a different pattern from FEs and PMs in both representational and deictic gestures (see supplemental material Figure S2). Overall, our findings

[8]We cannot, at this time, explain all individual differences in frequency. We do discuss why Incorporated FEs may be relatively less frequent in 4.4, using insights from conventionalized sign languages.

[9]Coppola et al. (2013) describe one UM incorporated into a deictic gesture and several instances of adult homesigners pointing at their own hands. This paucity is not surprising given that only 9% of the gestures that the adults produced during these number sessions were deictics (based on a review of the data coded for Coppola et al.'s analysis), compared to 39% for the children.

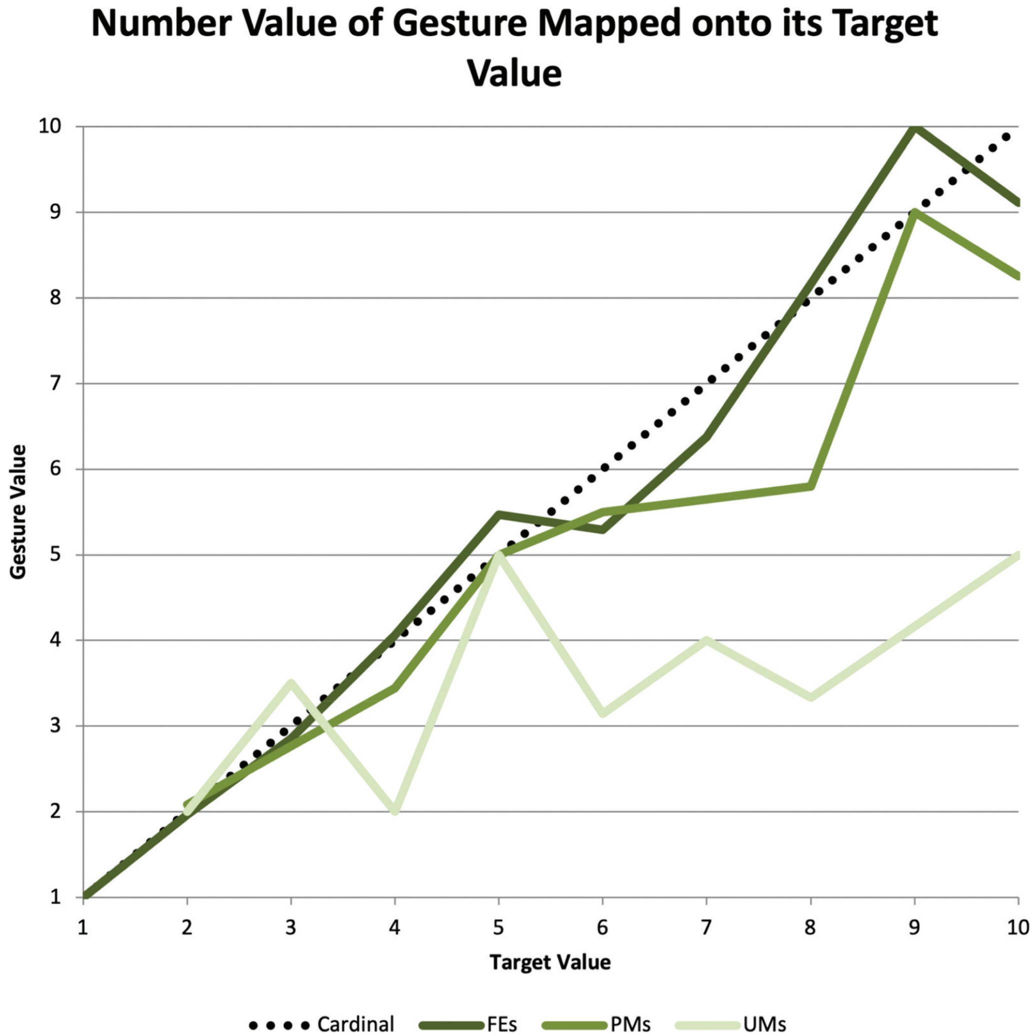

Figure 3. Gesture Value of Finger Extensions (FEs, darkest green line), Punctuated Movement repetitions (PMs, medium dark green line), and Unpunctuated Movement repetitions (UMs, light green line) plotted as a function of Target Value. A cardinal system in which the Gesture Value equals Target Value is plotted in the dotted black line for comparison. Gesture Values for FEs and PMs increase with Target Value (and approach the cardinal dotted line), whereas Gesture Values for UMs are relatively flat across Target Values, like a non-cardinal system. The graph displays the total frequency of FE, PM, and UM gestures across children, collapsed by gesture type. For a graph separating representational and deictic gestures, see supplemental material Figure S2.

support the hypothesis that homesigners are using FE, PM, and UM forms to express number meaning, and that these forms express number meaning differently––FEs and PMs are used to express cardinal-like number meaning but UMs express meaning non-cardinally (akin to a generic plural marker).

Overall accuracy of Gesture Value compared to Target Value

Another way of assessing the cardinality of number gestures is to calculate how accurately they encode Target Value. We expect cardinal number devices to exhibit higher overall accuracy than non-cardinal number devices. Figure 4 presents an accuracy assessment of the homesigners' number gestures using two metrics: the proportion of number gestures produced in which the Gesture Value exactly matches the Target Value (left graph), and the average absolute difference between the Gesture Value and Target Value (right graph). In both cases, the depiction uses the total frequency of gestures across all

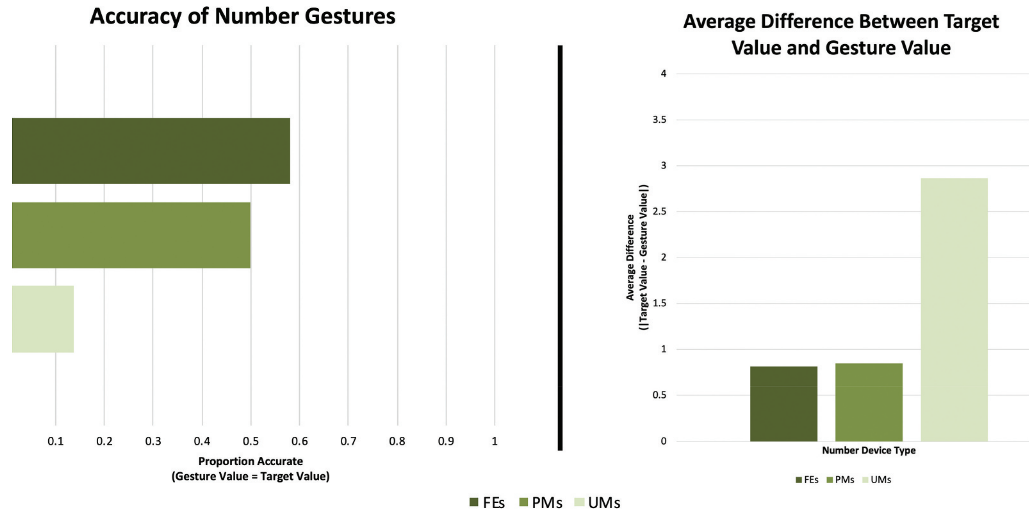

Figure 4. Two measures of how accurately number gestures express Target Value. The graph on the left depicts the proportion of number gestures with matching Gesture Value and Target Value. Here, higher bars reflect increased accuracy. As expressions of cardinal number, the proportion of accurate number gestures is higher for Finger Extensions (FEs) and Punctuated Movement repetitions (PMs); non-cardinal Unpunctuated Movement repetitions (UMs) have a lower proportion of matching Gesture Value and Target Value. The graph on the right depicts the average absolute difference between Gesture Value and Target Value (|Target Value – Gesture Value|). Here, lower bars reflect increased accuracy. Absolute differences for FE and PM devices are low, as would be expected of cardinal number expressions; absolute differences for UMs, however, behave like expressions of non-cardinal number and often exhibit large differences between the Gesture Value and Target Value. Proportions are calculated using the total number of FE, PM, and UM gestures across children collapsed by gesture type. For a depiction separating representational and deictic gestures, see supplemental material Figure S3.

homesigners collapsed across gesture types (see Figure S3 in the supplemental material for a depiction of these patterns separated into representational and deictic gestures).

As illustrated in Figure 4 (left graph; here a higher value reflects higher accuracy), a relatively high proportion of the homesigners' FEs (59%) and PMs (50%) matched the Target Value. In contrast, a much smaller proportion of homesigners' UMs matched the Target Value (14%).[10] Each of the four homesigners in our study had higher proportions of matching responses for FE and PM gestures than for UMs gestures.

A distinction between FEs and PMs versus UMs is also reflected in our second accuracy metric: the average absolute difference between the Gesture Value and Target Value (right graph in Figure 4; here a lower value reflects higher accuracy). For FEs and PMs, the average absolute difference between the Gesture Value and Target Value is around or below 1.0 (0.81 FEs; 0.85 PMs). For UMs, however, the difference is much higher: 2.9. Here, too, the patterns were consistent across homesigners.

Statistical tests further reinforced the similarity between FEs and PMs, compared to UMs, with respect to accuracy. We first used a one-way ANOVA with three groups (FE, PM, UM) to probe effects of number device type on all gestures. We found a statistically significant effect of number device type for both proportion of accurate gestures ($F = 7.316$, $p < .001$) and absolute difference between Gesture Value and Target Value ($F = 26.6$, $p < .001$). Post-hoc comparisons (Tukey HSD) showed that FEs ($p < .001$ proportion accurate, $p < .001$ average absolute difference) and PMs ($p = .008$ proportion accurate, $p < .001$ average absolute difference) were each significantly different from UMs, but not from each other ($p = .16$ proportion accurate, $p = .25$ average absolute difference).

[10]In a separate analysis that takes into consideration difficulties homesigners might have with counting, we assessed accuracy by classifying a Gesture Value as matching if it was ±1 off from the Target Value. Using this one-off metric, we find that FEs and PMs have increased accuracy across the board: 80% for FEs overall, 78% for PMs overall. In contrast, the proportion of accurate gestures for UMs remains relatively low: 32% overall.

We then used linear mixed-effects models to statistically probe whether the three number devices worked in the same way when incorporated into representational versus deictic gestures. Isolated FEs were excluded from this analysis. We constructed two models, one for each of our two measures of accuracy (matching Gesture Value and Target Value; absolute difference); each measure was included as a fixed effect, along with number device type (FE, PM, UM), and gesture type (incorporated into a representational vs. deictic gesture). In order to account for the fact that each homesigner did not contribute the same amount of data to the analysis, we also fit random intercepts for each participant (fitting random slopes was not possible due to a lack of data). A model comparison showed that device type (FE, PM, UM) accounted for a statistically significant amount of the variance for both accuracy measures (χ^2 = 12.153, p = .002, Gesture Value matches Target Value; χ^2 = 49.231, p < .001, absolute difference). To explore the possibility of an interaction between gesture type and device type, a loglikelihood ratio test was used to compare the fit of nested models that differed only in the presence of an interaction term for these factors. The interaction did not contribute significantly to model fit for either accuracy measure (χ^2 = 0.5715, p = .45 Gesture Value matches Target Value; χ^2 = 1.1283, p = .29 absolute difference). This analysis provides statistical support for the observation that the homesigners' number devices (FEs, PMs, UMs) do *not* behave differently when incorporated into representational versus deictic gestures.

To summarize thus far, in terms of both number tracking and our two measures of accuracy, UMs are consistently behaving like non-cardinal quantity expressions––they do not closely track quantity, and they exhibit relatively low proportions of matching Gesture Value and Target Value and relatively large differences between the two. In contrast, FEs and PMs are behaving differently and express number in a more exact, cardinal-like way––they track quantity relatively well, and they exhibit relatively high proportions of matching Gesture Value and Target Values; moreover, even when FEs and PMs are "wrong", the difference between their Gesture Value and their Target Value is relatively small.

Movement repetition and number meaning in Group Points and Group Sweeps

Group Points and Group Sweeps were, at times, produced with repetition (11 of 34 Group Points included movement repetition, as did 44 of 75 Group Sweeps), and we next asked if this movement repetition was numerically significant. As in UMs (3.2.1), repetitions did not systematically increase as Target Value increased (r = −.08 for Group Points, r = −.62 for Group Sweeps). Using the accuracy measures in 3.2.2, we also found that none of the Group Points repetition counts matched Target Value, and only 16% of Group Sweeps did.[11] With respect to the absolute value difference, we also found relatively large average differences between Gesture Value and Target Value (4.10 Group Points, 2.40 Group Sweeps). Although limited data prevent us from coming to a strong conclusion, the homesigners do not appear to be using repetition in Group Points or Group Sweeps to track the number of objects in a set. These findings are consistent with repetition in Group Points and Group Sweeps expressing non-cardinal number, as it does in UMs. However, another possibility is that repetition in these deictic gestures serves an emphatic or prosodic function (repetition serves a variety of functions in conventionalized sign languages). Because Group Points and Group Sweeps are compatible with both a singular (*the group*) and plural (*these objects*) interpretation, however, we continue to set them aside in terms of cardinality.

In terms of cardinality, the patterns we observe motivate a superordinate categorization of the homesigners' number devices as cardinal (FE, PM) versus non-cardinal (UM) number markers, as schematized in Table 2. These cardinal (FE, PM) and non-cardinal (UM) devices are combined with different gesture types – representational gestures functioning as predicates or nominals, and deictic gestures functioning as nominals – and, like morphemic units, contribute predictable numerical meaning, regardless of the base gesture into which they are incorporated. In other words, these number-marked gestures form a paradigm.

[11]We also assessed Gesture Value using our one-off "buffer" (see footnote 7) and found 5% accuracy for Group Points and 39% for Group Sweeps.

Table 2. Paradigmatic organization of homesigners' incorporated number devices. Incorporated number devices from Table 1 are organized by the type of gesture into which they were incorporated (predicate representational, nominal representational, nominal deictic). Numbers represent mean tokens produced across the four homesigners (standard deviation in parentheses). FEs are Finger Extensions, PMs are Punctuated Movement repetitions, and UMs are Unpunctuated Movement repetitions.

Incorporated Devices	Number	Predicate Representational Gestures	Nominal Representational Gestures	Nominal Deictic Gestures
Cardinal Devices	FE	1 (SD = .96)	1 (SD = 2.5)	3 (SD = 4.08)
	PM	5 (SD = 2.08)	2 (SD = 3.0)	22 (SD = 15.29)
Non-cardinal Devices	UM	2 (SD = 2.06)	2 (SD = 1.73)	3 (SD = 4.69)

Table 2 includes each of the paradigmatic combinations we observe and presents, for each member of the paradigm, the mean number of gestures produced by the four homesigners.[12] These findings suggest that homesigners can create compositional number expressions consisting of smaller, meaningful subparts. The transparency and systematicity of these form-meaning mappings supports our claim that their number marking has the hallmarks of an emergent morphological paradigm.

In conventional languages, morphology is but one component of linguistic structure. If these number-marking devices constitute an emergent morphological paradigm, as we propose, then we would expect them to be incorporated into syntagmatic structure, as is true of (number) morphology in established languages. We next turn to the homesigners' syntagmatic use of number-marked gestures.

Number marking in the homesign grammatical system

The homesigners produced a total of 1642 utterance units (460 CHS1, 273 CHS2, 623 CHS3, 286 CHS4), which we delimited and coded using the criteria described in Section 2.3. Of these, we identified 751 utterances (135 CHS1, 147 CHS2, 387 CHS3, 82 CHS4) that contained at least one gesture expressing codable propositional information (either a nominal argument or a predicate). We use these *propositional* utterances to examine how number functioned as a part of the homesigners' larger grammatical system.[13]

The average length of the homesigners' propositional utterances was 1.75 gestures (2.1 CHS1, 1.5 CHS2, 1.81 CHS3, 1.37 CHS4) and 225 (30%) contained number marking (see Table S3 in the supplemental material for a summary of gestures, utterances, and number-marking distribution).[14] Thus, the homesigners do not use their number devices only as standalone expressions of quantity, but as number markers incorporated into the propositional expressions of their emergent grammatical system. To explore homesigners' syntagmatic use of number devices, we first catalog the ways number devices are incorporated into predicate and argument components of propositions (3.3.1). In section 3.3.2, we then describe gesture order patterns of utterances with and without number. We also document and discuss the existence of complex utterances containing multiple expressions of number (3.3.3; see also 1.1.3).

How number devices are used in sentences

We classified the homesigners' propositional utterances into one of six types, summarized in Table 3 along with the number of each propositional utterance type produced by each child.[15] Type 1

[12]CHS2 produced two tokens of a representational gesture with a PM that could not be confidently classified as either a predicate or a nominal; these tokens are not included in Table 2 (but are included in Table 1).

[13]The remaining 891 (325 CHS1, 126 CHS2, 236 CHS3, 204 CHS4) utterances could not be clearly analyzed for propositional content or meaning (22 CHS1, 72 CHS2, 60 CHS3, 6 CHS4) or did not contain any gestures expressing propositional information (e.g., utterance units containing only pragmatic gestures such as an attention-getting wave of the hand; 261 total; 117 CHS1, 20 CHS2, 80 CHS3, 44 CHS4).

[14]We did not exclude single gesture utterances because child and adult homesigners often express propositional information using only a single gesture (and single "word" utterances are grammatical in many conventionalized languages).

[15]These utterance types overlap with those used by Coppola et al. (see their Table 2) and the child homesigners in our study produce all of the types of utterances that they report. However, having identified a morphological paradigm that includes nominal number marking, we are now able to identify new strategies for incorporating number into propositional utterances (argument marking).

Table 3. Propositional utterance types. Homesigners' propositional utterances classified according to whether number is marked within the utterance and, if so, how. The first four columns list the total count of each propositional utterance type produced by each homesigner, and the fifth column is the total count across all four homesigners; one instance of a Type 6 utterance (the listed example utterance) includes a multiply-marked argument and is also included in the count of Type 4 utterances. Conventional numbers and representational gestures are glossed in small caps (e.g., TWO, SHOOT-BASKETBALL). Subscripts gloss the type of number device using FE for Finger Extension, PM for Punctuated Movement repetition, and UM for Unpunctuated Movement repetition (e.g., FALL-OVER$_{UM}$). Subscripted "=#" glosses the number of movement repetitions (e.g., point$_{PM=3}$) or fingers extended (TWO$_{FE=2}$); number of fingers extended is also prefixed onto gesture glosses (8HS-point$_{FE=8}$).

				Example Utterance	CHS1	CHS2	CHS3	CHS4	Total
Utterance Type	1	No Number Marking		Form: point ELEPHANT point WALK Meaning: *An elephant is walking there.*	90	119	266	51	526
	2	Argument Number Marking	Isolated FE	Form: TWO$_{FE=2}$ point SHOOT-BASKETBALL Meaning: *Two [men] there shot basketballs.*	21	2	13	2	38
	3		Nominal Gesture w/Incorporated Number Marker	Form: point$_{PM=3}$ GONE Meaning: *Those [three lily pads] are empty.*	8	18	97	27	150
	4		Multiply-Marked Argument	Form: EIGHT$_{FE=8}$ point 8HS-point$_{FE=8}$ Meaning: *There are 8 [monkeys].*	6	0	5	0	11
	5	Predicate Number Marking	Predicate Gesture w/Incorporated Number Marker	Form: BASKETBALL SHOOT$_{PM=2}$ Meaning: *[Two men] shot basketballs.*	8	7	4	2	21
	6	Argument + Predicate Marking		Form: point$_{GS}$ TWO$_{FE=2}$ FALL-OVER$_{UM=2}$ Meaning: *Those two [cups] fell over.*	2	1	2	0	5

utterances are the utterances that contained no number marking; Types 2–6 utterances contain number marking on either an argument (Types 2, 3,4), predicate (Type 5), or both (Type 6).

In Type 2 utterances, number information was conveyed by an Isolated FE in an argument role. Similar to nominal ellipsis structures, homesigners produced Isolated FEs as the sole gesture representing an argument in an utterance. For example, the $\text{TWO}_{FE=2}$ standing in for the two men in (1). At times, however, Isolated FEs were also combined with a nominal gesture, as in the argument-only utterance in (2).

(1) $\text{TWO}_{FE=2}$ point (at laptop screen) SHOOT-BASKETBALL *Two [men] shoot basketballs.*

(2) $\text{TWO}_{FE=2}$ BIRD *Two birds*

In both (1) and (2), number information is expressed "lexically" by a standalone Isolated FE. In Type 3 utterances, number information is marked on an argument by incorporating a number-marking device into either a deictic or representational gesture – that is, morphologically. Like Isolated FEs, deictic gestures could serve a pronoun-like function as the sole gesture expressing an argument, (3).

(3) $\text{point}_{PM=3}$ (at picture) GONE *Those [three lily pads] are empty.*

The homesigners also sometimes combined their gestures to create complex multi-gesture arguments. If an argument contained more than one number marker, the utterance was classified as Type 4 (multiply-marked argument), which we discuss further in Sections 3.3.3 and 4.3.

Type 5 utterances contained a number-marked predicate. In these cases, a number device was incorporated into a predicate representational gesture, as with the movement repetition of SHOOT in (4).

(4) BASKETBALL $\text{SHOOT}_{PM=2}$ *[Two men] shot basketballs.*

In another case, (5), a homesigner produced a predicate with an incorporated FE handshape: $\text{7HS-PEEL-BANANA}_{FE=7}$, where seven fingers, each representing a banana, are extended and sequentially "peeled." The homesigner (CHS2) in this case combined the number-marked predicate with a separately produced number-marked nominal gesture, $\text{BANANA}_{FE=5}$.

(5) BANANA $\text{BANANA}_{FE=5}$ $\text{7HS-PEEL-BANANA}_{FE=7}$ *[The monkeys] ate five bananas.*[16]

Thus, the utterance contains number marking on *both* an argument and a predicate. We classified the small number of utterances of this type as Type 6 utterances (one of these utterances had a multiply-marked argument and is listed twice in Table 3). As with Type 4, we return to these utterances in Sections 3.3.3 and 4.3.

Gesture order and the structural patterns of utterances with and without number marking

We also conducted a preliminary examination of the order of subject and predicate in the homesigners' propositional utterances. We identified 61 propositional utterances (11 CHS1; 9 CHS2; 36 CHS3; 5 CHS4) that contained both an overt predicate and an overt subject-like argument, either an actor for act predicates or an entity for attribute or be-located predicates, and that could be coded for

[16]The proposition in (5) is translated using the Target Value, which the homesigner correctly codes on the argument but not the predicate.

the use of subject-predicate order.[17] We know from previous research (Goldin-Meadow et al., 2009) that child homesigners from the United States, China, and Turkey prefer to place the actor argument in a position preceding the act, and that child homesigners from the United States produce an entity-attribute ordering (Goldin-Meadow & Mylander, 1984). These patterns were also found in adult Nicaraguan homesigners studied by Coppola and Newport (2005), who argued that the patterns reflect a subject-predicate ordering bias.

We see the same patterns emerging in the child homesigners studied here. The subject-like arguments precede their associated predicate in 48 out of the 61 utterances (79%) and this pattern is true for all four of the homesigners. All four of the homesigners exhibit the preference for subject-predicate order in utterances with number marking (23/27, 85%), and three of the four exhibit it in utterances without number marking (25/34 or 74% across homesigners; CHS1 produced only 5 utterances without number marking and 2/5, 40%, followed subject-predicate order). The counts of propositional utterances in each set are small, preventing statistical analysis. However, these observations suggest that utterances with and without number marking exhibit similar emergent grammatical patterns (preference for subject-predicate order). This finding, too, supports the hypothesis that number marking is not an extra-grammatical feature, but is a component of the children's developing linguistic systems.

Multiple marking: combinations of number devices within an utterance

Three of the four homesigners produced utterances with multiple number markers (CHS4 did not produce any multiply-marked expressions). These utterances include agreement-like combinations where number was marked on both an argument and the predicate (CHS1, CHS2, CHS3), as well as combinations of multiple number markers within an argument (CHS1, CHS3), similar to number concord. These structures offer further insight into the homesigners' number language.

In (6), for example, the homesigner combines two distinct (and redundant) number devices, an Isolated FE ($\text{EIGHT}_{FE=8}$) and an FE incorporated into a deictic gesture (point $_{FE=8}$).

(6) $\text{EIGHT}_{FE=8}$ point (at screen) 8HS-point$_{FE=8}$ (at screen) *There are 8 [monkeys].*

Here, the homesigner is describing a vignette with eight monkeys and correctly expresses this number information in two distinct FE gestures. Notice, however, that the homesigner produces an unmarked pointing gesture (a point at the blank laptop screen) in between these two number-marked gestures. This pointing gesture suggests that the second FE is not perseveration of the handshape from the first and the two FEs are individually meaningful. Both accurately code the Target Value, affirming that FEs are produced with a cardinal intention.

The homesigners also combined different number device types, as in (7). Here, the homesigner produces an Isolated FE ($\text{THREE}_{FE=3}$) alongside an overt number-marked nominal gesture, $\text{CUP}_{PM=3}$, to describe a vignette in which three cups of juice fall over and spill. One of the more complex utterances produced by the homesigners, (7) also includes an overt predicate, FALL.

(7) $\text{THREE}_{FE=3}$ $\text{CUP}_{PM=3}$ FALL *Three cups fall.*

In addition to multiply-marked arguments like (7), the homesigners also produced five utterances containing number marking on both an argument and a predicate, as in (8).

(8) point$_{\text{group-sweep}}$ $\text{TWO}_{FE=2}$ $\text{FALL-OVER}_{UM=2}$ *Those two [cups] fell over.*

[17]We excluded bracketed structures like CUP FALL CUP, as these cannot be coded as subject-predicate or predicate-subject order (17 Total; 10 CHS1, 2 CHS2, 5 CHS3).

In the multiply-marked expressions in (6)-(8), the number devices all match in Gesture Value (as per the discussion in Section 3.2.3, we do not include a Gesture Value for the Group Sweep). The homesigners also produced multiply-marked utterances with distinct Gesture Values for the same referent object or action (i.e., for the same Target Value). In (9), for example, the homesigner is describing a vignette with six ice cream cones and produces two number devices, an Isolated FE and a PM incorporated into a deictic gesture.

(9) $\text{SEVEN}_{FE=7}$ $\text{point}_{PM=6}$ *Those 7 [ice cream cones].*

The PM here has a correct Gesture Value of "6" and the FE has an approximately correct Gesture Value of "7". In this case, mismatching Gesture Value likely reflects the impact of limited number knowledge on the children's number language (cf. Spaepen et al., 2011). However, the (approximate) accuracy of each device in (9) is consistent with the FE and PM both being used to express cardinal number information (see also (5) above).

In some cases, however, mismatching Gesture Values provide further evidence that the homesigners are *distinguishing* cardinal and non-cardinal number markers. In (10), the homesigner describes a group of ten sheep using an Isolated FE ($\text{TEN}_{FE=10}$) at the beginning of their description and repeated again at the end. The Gesture Value ("10") of both FEs match the Target Value of the referent, as would be expected of a cardinal number marker. In between the two FEs, however, the child produces an index finger pointing gesture with an incorporated UM with four repetitions ($\text{point}_{UM=4}$).

(10) $\text{TEN}_{FE=10}$ $\text{point}_{UM=4}$ $\text{TEN}_{FE=10}$ *There are 10 [sheep]*

As with (6), the intervening gesture suggests that the two FEs are individually meaningful (not the consequence of handshape perseveration). The Gesture Value ("4") of the UM differs substantially from the Target Value. This mismatch is not likely the result of the homesigner mis-counting––they correctly code "10" in the FEs. Rather, combinations like (10) provide further evidence for the (non-) cardinality of the homesigners' number devices: FEs express number cardinally and UMs express number non-cardinally, so the number devices in (10) are expressing distinct but compatible numerical information.

Discussion

Quantity is central to how we understand the world, and all known languages have linguistic tools for expressing number. Coppola et al. (2013) showed that adult homesigners and one child homesigner innovated handshape (FEs) and movement repetition (PMs, UMs) as number-marking devices with predicate representational gestures. We found these number forms in three additional child homesigners, none of whom interacted with one another. We also documented new strategies for expressing number information (Group Points, Group Sweeps). But the innovative theoretical contribution of our findings is that the homesigners also incorporate number-marking devices into representational and deictic gestures functioning as nominals. These newly-identified combinations allow us to see the morphological structure underlying the homesigners' number language. Importantly, the meaning contribution of FEs, PMs, and UMs is consistent and predictable across gesture types, and the meaning of the complex, number-marked gestures can be compositionally derived from the meaning of their parts.

The homesigners' number language thus exhibits the form and meaning correspondences of an emergent *morphological paradigm*. The homesigners also exhibit productivity and systematicity in how they incorporate number gestures into their broader communication system. They produce propositional utterances that contain number expressions (sometimes multiple number expressions within an utterance) and these utterances exhibit patterns in gesture order, akin to an emergent *syntactic* system. These findings inform our understanding of the resilience of number language (4.1) and the expression of number in emergent grammars (4.2 and 4.3). Moreover, similarities across homesign systems, and between homesign and conventional (sign) languages, suggest that there is resilience not only in *whether* number is expressed, but also in *how* number is expressed (4.4). We discuss each of these implications in turn.

Number language is resilient and robust

Coppola et al. (2013) found that adult homesigners systematically used FEs, PMs, and UMs to signal cardinal (FE, PM) and non-cardinal (UM) number, and integrated these number gestures into complex utterances. They also found that hearing communication partners of the adult homesigners' produced fewer complex gestural utterances than did the homesigners, did not integrate number markers into their utterances in the same way as homesigners, and did not appear to produce their UM gestures with a genuinely non-cardinal intention. Coppola et al. conclude from these findings that the number devices are innovated by the homesigners themselves. This suggestion finds further support in Coppola et al.'s (2013) analysis of one child homesigner (CHS1 in our study). This homesigning child produced number gestures that more closely resembled the number gestures produced by the adult homesigners (who the child did not know) than those of his own hearing mother (who communicated with him daily).[18] These findings are consistent with previous work showing that child homesigners in the United States produce gestures that are structured differently from those of their hearing parents (Goldin-Meadow & Mylander, 1983, 1984, 1998; Goldin-Meadow et al., 1995, 2007; Hunsicker & Goldin-Meadow, 2012). There is thus good reason to believe that the number devices used by homesigners do not originate in their communication partners.

These devices are, then, *resilient* in the sense of Goldin-Meadow (1982). Our study further probes the resilience of number language in homesign by examining the burgeoning communication systems of four child homesigners. Each of these children lacks a conventional language model and is developing and using an idiosyncratic homesign system. For each of them, this homesign system includes mechanisms for expressing cardinal (FE, PM) and non-cardinal (UM) number meaning.

Further evidence for the resilience of number language comes from our observation that all four of the homesigners studied here use these number devices in other communicative situations – not only in our experimental activity designed to elicit communication about number, but also in non-number experimental tasks and in spontaneous communication. In other words, the number devices are genuinely part of the homesign systems and are not created *de novo* in the context of the number vignettes. For example, in describing an unrelated vignette (from a different task, Horton et al., 2015) in which a human agent puts cigars on a table, CHS4 incorporated two punctuated movement repetitions into a PUT-DOWN gesture ($\text{PUT-DOWN}_{PM=2}$). In spontaneous communication, CHS2 used multiple Isolated FEs to request and describe toy figurines while playing, and CHS3 incorporated 2-handshape FEs into deictic gestures indicating pictures of pairs of socks and gloves. Also in spontaneous communication, CHS1 incorporated 4 unpunctuated movement repetitions into a PUT-DOWN-MARBLE gesture ($\text{PUT-DOWN-MARBLE}_{UM=4}$), after which the homesigner traced a circle in space (the picture the homesigner was describing depicted marbles inside of a circle) and produced another UM, this time incorporated into a deictic gesture ($\text{point}_{UM=4}$). Thus, even when information about quantity is not targeted, the child homesigners use their number devices, and do so in ways that affirm our observations regarding productivity and cardinality.

We also have evidence that this phenomenon is cross-culturally robust. Since identifying these number devices in Nicaragua, we have been able to document their existence in early recordings of child homesigners in the United States, with both representational and deictic gestures. One American homesigner (male, age 2;05) described a picture of gum drops by incorporating two punctuated

[18]We did not have recordings of the regular communication partners of all the additional homesigners in our study so we were not able to examine how they expressed number in their (co-speech) gesture.

movement repetitions into a representational gesture referring to how the candy would be eaten ($\text{PICK-UP-AND-PUT-IN-MOUTH}_{PM=2}$). Another homesigner (male, age 3;05) incorporated movement repetition into a variety of deictic gestures: three unpunctuated repetitions were incorporated in reference to the pages of a newspaper ($\text{point}_{UM=3}$), 10 punctuated repetitions were incorporated into a deictic to refer to the rungs of a ladder ($\text{point}_{PM=10}$), and four or five repetitions were incorporated into a deictic gesture to refer to a group of people having lunch (the recordings were made in the 1970's and the video quality makes it somewhat more difficult to identify exact count and distinguish movement types). In the same session, this homesigner also incorporated a 2-handshape FE into a deictic gesture to refer to two blocks. Although detailed examination of the spontaneous number language of the Nicaraguan and United States children is outside the scope of the present research, these observations provide additional, ecologically valid evidence for the robustness and resilience of number in homesign and, thus, in language more generally.

Number as a morphological paradigm

The communication systems innovated by homesigners reveal cognitive and structural biases that shape language. The division between cardinal (FE, PM) and non-cardinal (UM) number devices is a distinction found in number language in conventionalized languages (e.g., the English cardinal *three* versus non-cardinal generic plural *cups*). The appearance of a cardinality distinction in homesign suggests that it is a fundamental distinction in how we think about and express number.

In terms of linguistic structure, the four child homesigners produce incorporated FEs, PMs, and UMs with consistent meaning across gesture types (representational, deictic) and grammatical functions (predicate, nominal). Coppola et al. (2013, footnote 4) report only one number-marked nominal in their study and speculate that the animated events in their stimuli (which are identical to ours) focused the homesigners' attention on actions and locative relations, rather than on sets of to-be-named objects. The static pictures in our study may have increased the child homesigners' focus on objects. This may explain why there are a relatively large number of number-marked nominal representational gestures in our data (17 tokens, 7 types total; 3 tokens, 1 type CHS2; 14 tokens, 6 types CHS3; CHS1 and CHS 4 produced no number-marked representational gestures coded as nominals; all four homesigners produced number-marked deictic nominals). Regardless of the explanation, the patterns we observe nevertheless reveal that FEs, PMs, and UMs are productive in the sense that they are combined with a variety of forms (not in the sense that they are frequently used – some children use the forms frequently, others do not). Each form is independently meaningful, akin to an inflectional unit, and part of an emergent morphology for number. These meaningful morphemic number markers can be combined with representational and deictic gestures to generate new, complex meanings.

Crucially, these combinations create compositional meanings using the lexeme meaning of the base gesture and the cardinal or non-cardinal meaning of the incorporated number marker. These findings are consistent with previous work documenting morphological regularities in the creation of the gesture base itself: homesigners in the United States (Goldin-Meadow et al., 1995) and China (Goldin-Meadow et al., 2007) systematically combine handshapes and motions to derive gestural "lexemes" in which the meaning of the whole is the sum of the two parts. However, in the case of the number language studied here, the homesigners are able to *build onto* these gesture bases by combining them with productive number-marking forms that generate new meaning complexes. Our findings show not only that *expressing number* is a resilient property of language, but so too is the grammatical capacity to generate expressions with regular paradigmatic morphological structure. Whereas previous research documented this phenomenon in the domain of lexical *formation*, regularities in the homesigners' number language provide evidence for emergent paradigms of lexeme *inflection*.

Morphological complexes as part of a communication system

The homesigners produce isolated number devices in argument roles, as well as embedded number devices incorporated into both argument and predicate roles. Moreover, a preference for subject-predicate order in utterances with and without number-marking provides preliminary evidence of structural similarity across propositions. Homesigners incorporating these paradigmatic structures into their utterances informs our understanding of the syntactic system and the syntagmatic properties of homesign.

This syntactic system is one that can generate utterances containing *multiple* expressions of number. Moreover, based on how the Gesture Values of these combinations converge and diverge, we argue that multiply-marked expressions provide additional support for cardinality distinctions in the number paradigm. Multiple number devices within an utterance could express identical numerical information with matching Gesture Values, as in (6)-(8). However, the homesigners also produced utterances with multiple number devices with non-identical Gesture Values. Such productions may arise because the homesigners' gestures are not meaningfully numeric (unlikely given our findings). They may also arise due to linguistic or mathematical errors (we leave as an open question how the homesigners' number knowledge relates to their use of number language). More relevant for the present research is that divergent Gesture Values can arise from meaningful differences in the *kind of quantity information* encoded. This explanation is the one we propose for cases like (10), where the homesigner combines a "correct" cardinal number marker (FE with Gesture Value "10") with a non-cardinal UM that diverges significantly from the Target Value (Gesture Value "4").

Combinations of number markers with greater (e.g., cardinal) or lesser (e.g., non-cardinal) specificity are well-attested in the utterances of conventional languages (e.g., *ten cows*, which combines cardinal *ten* plus non-cardinal *-s*). Moreover, patterns like those in Type 4 (multiply-marked argument) and Type 6 (marked argument and predicate) utterances resemble the "number concord" and "number agreement" patterns, respectively, that arise in many conventionalized languages. As noted earlier, syntagmatic number marking patterns such as these are relatively unexplored in sign languages. We know of no documented case of an obligatory number-marking dependency in a sign language. There are, however, documented cases that show multiple markers are possible in some sign languages, such as FIVE BOOK++ (*five books*) in Italian Sign Language (Pizzuto & Corazza, 1996). The homesigners in our study seem to be using a system that permits multiple markers of number, like Italian Sign Language. We next turn to how the homesign number markers themselves compare to those that have been documented in conventionalized sign languages.

Similarities between number expression in homesign and conventional sign languages

The appearance of homesign number markers across individuals, contexts, and cultures is likely not accidental. As noted earlier, these number markers are similar in both form and meaning to those documented in conventionalized sign languages. The FEs, PMs, and UMs produced by the homesigners in our study are similar to the numeral incorporation (FEs) and reduplication (PMs, UMs) that code number in conventionalized sign languages. Moreover, these number forms have the properties that Aronoff et al. (2005) suggest characterize early morphological developments in sign languages–– both FEs and movement repetition code numerical meaning in an iconically motivated way, as the fingers extended or movements produced represent quantity (even UMs iconically represent a multiplicity, if an inexact one).

We have also discovered a similarity between homesign and conventional language at higher levels of analysis. Established sign languages use the same markers to express number on nominal, verbal, and deictic signs, a parallelism that highlights the paradigmatic possibilities of a morphological system. We see the same parallelism in the homesigners' number language. Because homesign is arguably a contributor to the early stages of most (if not all) conventional sign languages (Coppola & Senghas, 2010; Cuxac, 2005; Fusellier-Souza, 2006; Goldin-Meadow, 2010), it is not surprising that morphological symmetry and parallelism of this type persist in established sign languages. In the Nicaraguan context, homesign patterns may also offer insight into the emergence and development of grammatical structures for number in Nicaraguan Sign Language (NSL), and we are currently in the process of documenting and analyzing number language in NSL (see Flaherty & Senghas, 2011, for some discussion of standalone numeral signs).

Patterns in conventional sign languages may also shed light on why only two of the four homesigners in our study incorporated FEs into representational gestures, whereas all four incorporated movement repetition (PMs or UMs) into representational gestures. Numeral incorporation is morphologically constrained in established sign languages, and is typically restricted to a small set of lexical items (similar to so-called "minor number" systems in spoken languages, Corbett, 2000; Corbett, 1996). This restriction may be because handshape bears a heavy lexical load in sign languages. Changing the handshape (as in numeral and FE incorporation) may overly obscure meaning, especially compared to movement changes, which are used in many distinct and productive morphological processes in established sign languages. Whatever the explanation, the relatively limited use of incorporated FEs in homesigners parallels the limited use of numeral incorporation in established sign languages.

These observations highlight the similarities between homesign and conventional languages – limits and exceptions to paradigmatic regularities are not uncommon in number systems, or in other morphological domains. Similarities between homesign and conventional language are expected given that homesigners have the same capacity for language as all typically developing humans. Moreover, such similarities help make clear how language experience does and does not constrain grammatical structure. Homesigners lack a language community and typical language input and experience, but are nevertheless able to innovate number paradigms, and to do so in ways reminiscent of number marking in conventionalized language. Together, these observations show not only that number itself is a resilient and fundamental property of human language, but so, too, are specific strategies for expressing number and structuring number language, especially in the sign modality.

Conclusion

In the absence of linguistic input, deaf homesigners are able to develop gestural communication systems that contain isolated expressions for number (comparable to conventional number words), as well as number markers that are incorporated into other gestures (comparable to morphological number marking). These devices are similar to forms found in conventional sign languages, and they differentially code cardinal (FE, PM) and non-cardinal (UM) meaning. Moreover, these number devices are combined with representational *and* deictic gestures in both predicate *and* nominal roles, illustrating an emergent morphological paradigm for marking number. Thus, the homesigners' number devices are similar in both form *and meaning* to number markers found in conventional languages. Both isolated and incorporated number markers are systematically produced in propositional utterances and thus are also part of the emergent (morpho)syntactic system of homesign. Similarities across homesigners and between homesign and conventional (sign) languages provide evidence for the centrality of number in human cognition and language and reveal the structural biases that shape linguistic communication.

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