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Communicating about quantity without a language model: Number devices in homesign grammar

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A B S T R A C T

All natural languages have formal devices for communicating about number, be they lexical (e.g., *two*, *many*) or grammatical (e.g., plural markings on nouns and/or verbs). Here we ask whether linguistic devices for number arise in communication systems that have not been handed down from generation to generation. We examined deaf individuals who had not been exposed to a usable model of conventional language (signed or spoken), but had nevertheless developed their own gestures, called *homesigns*, to communicate. Study 1 examined four adult homesigners and a hearing communication partner for each homesigner. The adult homesigners produced two main types of number gestures: gestures that enumerated sets (cardinal number marking), and gestures that signaled one vs. more than one (non-cardinal number marking). Both types of gestures resembled, in form and function, number signs in established sign languages and, as such, were fully integrated into each homesigner's gesture system and, in this sense, linguistic. The number gestures produced by the homesigners' hearing communication partners displayed some, but not all, of the homesigners' linguistic patterns. To better understand the origins of the patterns displayed by the adult homesigners, Study 2 examined a child homesigner and his hearing mother, and found that the child's number gestures displayed all of the properties found in the adult homesigners' gestures, but his mother's gestures did not. The findings suggest that number gestures and their linguistic use can appear relatively early in homesign development, and that hearing communication partners are not likely to be the source of

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homesigners' linguistic expressions of non-cardinal number. Linguistic devices for number thus appear to be so fundamental to language that they can arise in the absence of conventional linguistic input.

1. Introduction

All of the world's languages provide ways to communicate about number. However, languages vary widely in whether and how they encode information about quantity (Corbett, 2000). They vary in which aspects of number are encoded, whether number information appears on nouns, verbs, and/or other grammatical elements, and whether agreement between linguistic categories marked for number (e.g., agreement between subject and verb, or between adjective and noun) is required. Number marking frequently takes the form of a lexical item that indicates an exact (e.g., *five*) or approximate (e.g., *some*) quantity. This lexical item can be used to modify an argument in the sentence (e.g., *five boys play; some boys play*) or to stand in for the argument (e.g., *five play; some play*). But number devices can also be grammatical and affixed to a noun (e.g., the plural *-s* marker on the noun, *boys*) or verb (e.g., the verb *plays*, which agrees with the singular subject *one boy* in *one boy plays*). Some languages, such as English, have both lexical and grammatical ways of marking number. However, other languages have only one system; for example, Khmer has number words, but does not have a singular-plural distinction or any other grammatical number marking (Diffloth, 1992). Here we ask whether number devices, both lexical and grammatical, are so central to language that they can appear in a communication system developed by an individual who has not been exposed to a conventional language. To address this question, we turn to a rare population—homesigners.

Homesigners are deaf individuals whose hearing losses prevent them from acquiring the surrounding spoken language, and who have not been exposed to conventional sign language (Goldin-Meadow, 2003; Goldin-Meadow & Feldman, 1977; Goldin-Meadow & Mylander, 1983, 1998). Although they have not acquired a conventional language, these deaf individuals develop gesture systems, called *homesigns*, to communicate with the hearing people in their worlds. These homesign systems have been shown to have many, though not all, of the properties found in natural languages: for example, grammatical categories of nouns, verbs, and adjectives (Goldin-Meadow et al., 1994); the grammatical relation of subject (Coppola & Newport, 2005); nominal constituents (Hunsicker & Goldin-Meadow, 2012); proto-pronouns (Coppola & Senghas, 2010); generics (Goldin-Meadow, Gelman, & Mylander, 2005); sentence-level markers of thematic roles (Goldin-Meadow & Mylander, 1984, 1998), word-level morphological structure (Goldin-Meadow, Mylander, & Butcher, 1995; Goldin-Meadow, Franklin, & Mylander, 2007), recursion (Goldin-Meadow, 1982), and negative and question sentence modulators (Franklin, Giannakidou, & Goldin-Meadow, 2011). However, no studies to date have examined whether or how number is marked in homesign systems.

We conducted two studies to explore number devices in homesign. Study 1 examined four congenitally deaf adults in Nicaragua who have used their own homesign systems to communicate with the Spanish-speaking hearing people in their worlds for their entire lives; we also studied a long-time communication partner for each of the four homesigners. Study 2 explored the developmental history of such systems by examining one child homesigner in Nicaragua and his hearing mother. We explore the homesigners' number expressions from two perspectives.

First, we ask how their gestures for number correspond to their thinking about number. Carey (2009) proposes two conceptual systems for number that are shared by humans and other animals. The *parallel individuation* system precisely tracks the individuals in sets containing from 1 to 3 items. The *analogue magnitude* system provides approximate representations of quantities larger than 3. We know from previous work that homesigners use their gestures to represent number—they extend different numbers of fingers when asked to represent different numbers of target items (Spaepen, Coppola, Spelke, Carey, & Goldin-Meadow, 2011). The ways that homesigners use their number gestures reflect these two conceptual systems. Homesigners extend the exactly correct number of fingers when representing small numbers, that is, sets containing from 1 to 3 items, and they extend an approximately correct number of fingers when representing large numbers; for example, to represent 8 items, they might raise 7, 8, or 9 fingers.

In the current study, we ask whether homesigners have ways of communicating about number that go beyond isolated gestures in which they extend their fingers, and whether they use these devices for both small and large numbers. We ask how the adult homesigners map their number gestures onto the objects they are attempting to describe; that is, we explore the relation between number gestures and the referential world. More specifically, we ask whether homesigners have non-cardinal number devices (devices that express more than one without indicating the exact number of objects, e.g., the plural affix —*s* on nouns in English), as well as the cardinal number devices (devices that express a specific number of objects, e.g., *five* in English) that they have been shown to have in previous work. In this way, we use the homesigners' gestures as a way of understanding their thinking about number.

Second, we examine how homesigners' concepts relating to number are expressed linguistically. Specifically, we ask whether their number gestures are lexical items that function as arguments and predicates in their gesture sentences, and whether the utterances they produce that contain number gestures follow the grammatical rules of homesign. In other words, we explore the relation between number gestures and other gestures in the sentence, and thus ask whether homesigners have *linguistic* ways of indicating number.

We also explore the source of the homesigners' number devices. It is quite likely that homesigners learn to extend their fingers to represent the number of items in a set from watching the hearing individuals around them. But do they learn the lexical and grammatical uses of their number gestures from the gestures hearing speakers produce? To explore this question, we examine the gestures that the adult homesigners' hearing communication partners produce when interacting with them. All four of the homesigners' communication partners were Spanish speakers. Spanish obligatorily marks number on arguments and predicates. All nouns, pronouns, determiners, and adjectives must be marked for number (singular, plural), and all elements within a noun phrase must agree in number marking. For example, in the noun phrase "L<u>os</u> niñ<u>os</u> content<u>os</u>" (the happy children), each element bears the suffix "-os" which marks it as plural (and masculine, Spanish noun phrases must also agree in gender). Subject noun phrases must also agree in number with the verb; for example, "Los niños contentos caminan". Here, the verb *caminar* (to walk) takes the third person plural ending, *-n*. If the gestures that the homesigners' communication partners produce follow the grammatical patterns found in their speech, and if those gestures serve as a model for the homesigners' gestures, we might expect to see gestural patterns that mirror number-marking in Spanish in both the adult homesigners and their communication partners.

To determine whether the patterns identified in the adult homesigners' number gestures appear relatively early in development, in Study 2 we conducted the Study 1 analyses on the number gestures produced by a 7-year-old child homesigner and his hearing mother. Children acquiring spoken Spanish mark number on nominal elements before verbal elements (Marrero & Aguirre, 2003). Agreement within the noun phrase for number and gender appeared by 2; 1 (years, months) in two children studied by Snyder et al. (2001). Around the time they begin to produce verbal inflections, children show evidence that they understand the number agreement system (Marrero & Aguirre, 2003). The homesigning child in Study 2 was 7 years old when we observed him and thus would have been expected to develop linguistic devices for number marking had he been exposed to a language model. Our question is whether the child was able to develop lexical and grammatical ways of referring to number in his homemade communication system even without input from a language model.

Previous work suggests that adult (Coppola & Senghas, 2010) and child (Goldin-Meadow, Franklin, & Mylander, 2005) homesigners can appropriate the gestures that hearing speakers produce and integrate them into their homesign systems. Given that homesigners observe hearing speakers holding up their fingers to express quantities, it would be surprising if they did not use gestures of this sort. However, homesigners might go beyond the patterns manifested by hearing speakers. If adult homesigners incorporate number gestures into their gesture systems as arguments and predicates and their communication partners do not, even after many years of interacting with the homesigners, we would have evidence that homesigners are able to go beyond their "input" to develop linguistic expressions of number. If the same patterns are found in a child homesigner's gestures and not in his mother's gestures, we would have further support for the resilience of *linguistic* number devices.

2. Study 1. Number gestures in adult homesigners and their communication partners

2.1. Method

2.1.1. Participants

Four adult deaf homesigners living in Nicaragua participated in the study. They ranged in age from 20 to 29 years, and one was female. The homesigners had no congenital cognitive deficits, had not learned spoken or written Spanish, and had not acquired Nicaraguan Sign Language (NSL). None had attended school regularly. The homesigners did not interact with one another and each developed a homesign system of his or her own (Coppola, 2002; Coppola & Newport, 2005). They use homesign exclusively to communicate with the hearing individuals around them. Each homesigner works, makes money, and interacts socially with hearing friends and family. To elicit communication about number, we asked each homesigner to watch short animated scenes and retell them to a hearing communication partner, who was either a relative or friend with whom the homesigner routinely interacted.

To get a sense of the number gestures that the homesigners saw in their daily lives, we also asked each communication partner to describe the scenes to the homesigner. Communication partners ranged in age from 21 to 56 years of age, and varied in their relationship to the homesigner: friend for Homesigner 1 (HS1), younger brother for Homesigner 2 (HS2), mother for Homesigner 3 (HS3), younger sister for Homesigner 4 (HS4). As described earlier, all of the communication partners were hearing, monolingual Spanish speakers. Moreover, none knew Nicaraguan Sign Language or any other sign language. Each of the adults' communication partners had had at least twelve years' experience communicating with his or her respective homesigner.

Table 1
Descriptions of the vignettes shown to the homesigners and their communication partners.

Item	Set A	Set B
1	2 Elephants enter one at a time.	1 Elephant enters
2	1 Bear sitting on a chair; bear falls off chair	2 Bears sitting on chairs; each bear falls off its chair 1 at a time.
3	8 Monkeys enter one by one, 7 are holding bananas, all 7 eat bananas simultaneously, 7 leave one by one, leaving the 1 monkey who doesn't have a banana	7 Monkeys enter one by one, 4 are holding bananas, all 4 eat bananas simultaneously, 4 leave one by one, leaving the 3 monkeys who don't have bananas
4	4 Flower boxes are in a row. 1 flower grows out of 3 of the boxes, 2 small flowers grow out of 1 box (5 flowers total)	6 Flower boxes are in a row. 2 flowers grow out of 5 of the boxes, 1 large one grows out of 1 box (11 flowers total)
5	5 Cups are in a row on a table. Each becomes filled with juice one at a time (3 orange, 2 red), then 2 fall over one at a time	6 Cups are in a row on a table. Each becomes filled with juice one at a time (3 orange, 3 red), then 3 fall over one at a time
6	8 Frogs are on lily pads in a random arrangement. 4 jump away all at once, 2 come back one at a time	12 Frogs are on lily pads in a random arrangement. 5 jump away all at once, 3 come back one at a time
7	10 Sheep are in a pen. 5 leave the pen, 1 is injured by a wolf, 4 return to the pen	10 Sheep are in a pen. 3 leave the pen, 1 is injured by a wolf, 2 return to the pen
8	6 Ice cream cones are in a random arrangement. 1 teddy bear enters 6 times, going to each cone once; bear eats 3 of the 6 ice creams (leaves cones), thus leaving 3 uneaten; bear stays by one of the uneaten ice creams but doesn't eat it	6 Ice cream cones are in a random arrangement. 1 teddy bear enters 6 times, going to each cone once; bear eats 5 of the 6 ice creams (leaves cones), thus leaving 1 uneaten; bear stays by last uneaten ice cream but doesn't eat it
9	6 Straws are in a cup containing juice. 6 birds come in one at a time, each drinks from a different straw; very little liquid is left in the cup at the end	5 Straws are in a cup containing juice. 5 birds come in one at a time, each drinks from a different straw; very little liquid is left in the cup at the end
10	A man shoots an orange basketball through a hoop 9 times, then leaves; a second man enters, shoots a yellow basketball through the hoop 8 times	A man shoots an orange basketball through a hoop 5 times, then leaves; a second man enters, shoots a yellow basketball through the hoop 10 times

2.1.2. Materials and procedure

Participants were videotaped describing ten 10- to 20-s vignettes with varying numbers of objects and events (Table 1 presents descriptions of all of the vignettes). For example, in one vignette, 8 frogs sat on lily pads, 4 jumped away all at the same time, and 2 returned one at a time. The vignettes were piloted with hearing American children prior to their use with the homesigners to ensure that they elicited talk about number. The vignettes were organized into two sets of 10, which were identical except for the particular numbers of objects and events depicted (e.g., 8 frogs in Set A vs. 12 frogs in Set B).

The experimenter played each vignette to the homesigner once in the presence of his or her communication partner, who could not see the computer screen. The experimenter then closed the computer and encouraged the homesigner to relay the events in the vignette to the partner. The experimenter conveyed the instructions to the homesigner using gesture only, though very minimal instructions were required as it was obvious from the set up that the homesigers were expected to describe what they saw on the screen. Every attempt was made to focus the homesigners' attention on the number of objects or events. If the homesigner did not provide information about the number of objects or events, the experimenter replayed the event and pointed out the objects while the stimulus was playing or, using gesture, encouraged the homesigner to provide more details about the quantities of objects and events. In addition, the experimenter often asked the hearing partner to encourage the homesigner to provide more information. The experimenter either gestured or spoke to the partner in Spanish; the partner then gestured to the homesigner, typically requesting information by indicating the computer screen with a manual or head point. These requests often included gestures that the homesigners had just produced, accompanied by a gesture glossed as "COUNT" in Nicaraguan hearing culture (touching the fingers of one hand with the index finger of the other hand in rapid succession, while simultaneously tilting the chin up and raising the eyebrows). Occasionally the partner would ask the homesigner about a specific number of objects or events by, for example, holding up eight fingers while producing the head tilt and raised eyebrows. All communication partners routinely used gestures to communicate with the homesigners; some occasionally supplemented their gestures with spoken or mouthed Spanish words.

All homesigners were tested twice on this task, once with each set of 10 vignettes; one set was presented at the beginning of the first session, and the second set was presented near the end of all testing sessions (at least 24 h later and after a series of other tasks assessing number cognition, Spaepen et al., 2011). Order of presentation of the sets was counter-balanced across homesigners. The data described here include each homesigner's performance on only the first set tested, with one exception; both sets were included in the Clause Type (Table 2) and Gesture Order (Fig. 4) analyses for Homesigner 4, who produced too few utterances to allow statistical analyses in the first set. Communication partners described the vignettes only once, and saw the same set that the homesigner described first. Two homesigners and their partners described Set A; two homesigners and partners described Set B.

2.1.3. Coding and analysis

2.1.3.1. Classifying number gestures. The gestures produced by the homesigners and their partners were transcribed and given English glosses following the procedure developed by Goldin-Meadow and Mylander (1984). Gestures referring to number were further categorized into 3 types (see Fig. 1; video examples are available in online Supplementary materials).

(1) *Finger Extensions (FEs)* were handshape configurations in which each extended finger indicated a member of the target set. For example, a hand with the index, middle, and ring fingers raised was coded as representing the value "3," as was a hand with the middle, ring, and pinky fingers raised (i.e., 3 different fingers, see also Fig. 1, top left). Finger Extensions could be one- or two-handed and, for values over 10, included sequential movements. For example, to express the value "12," all fingers of both hands were extended and moved forward palms out, quickly followed by a hand with 2 fingers extended. Finger Extensions could stand alone but they could also be incorporated into other gestures. For example, Homesigner 2 produced a *go* gesture using a handshape with 4 fingers extended to describe the vignette in which 4 sheep left the pen, that is, *4 + go* (see also Fig. 1, top right, in which a 2-FE is incorporated into the gesture *grow*).

Table 2
Types of clauses produced by homesigners (HS) and their communication partners (CP), classified according to the role(s) assumed by the number device[a].

Number marking[b]		Clause elements[c]	Examples	Gloss	Pair 1		Pair 2		Pair 3		Pair 4	
					HS	CP	HS	CP	HS	CP	HS[d]	CP
No number marking	1	(N)[b] P	BEAR FALL	A bear or many bears fall.	26	11	39	6	30	12	52	3
Lexical number	2	C (N) P	NINE JUMP	Nine (monkeys) jump.	9	12	44	22	69	6	20	5
Number-marked predicate	3	(N) P_C	CUP $FALL_{C(2)}$	Two cups fall.	6	9	9	3	9	3	4	0
	4	(N) P_{NC}	$GROW_{NC}$	Many (flowers) grow.	21	5	13	2	8	2	16	2
Lexical number + number-marked predicate [e]	5	C (N) P_C	Points-at-TWO-extended-fingers $FALL_{C(2)}$ DONE	Two (cups) fall.	5	5	9	5	19	3	5	0
	6	C (N) P_{NC}	SIX STRAW CUP Point-inside-cup BE-$LOCATED_{NC}$	Six straws are located inside a cup.	10	4	14	2	11	1	11	2

[a] P = Predicate; P_C = Predicate with a cardinal number marker, with the number in parentheses indicating the number of fingers or movements incorporated into the predicate; P_{NC} = Predicate with a non-cardinal number marker; HS = Homesigner; CP = Communication Partner.

[b] Lexical number signs (C = cardinal) are finger extensions that either modify or substitute for a nominal, or points to extended fingers that function as nominals (stand-ins).

[c] The parentheses around the noun (N) indicate that it is optional; the homesigners can either explicitly produce a sign for the N (as in examples 1, 3, and 6) or use a lexical number sign (C) as a substitute for the N (as in examples 2 and 5).

[d] Homesigner 4's values reflect her productions on the task two times; if we include only the numbers from the first set, the pattern is essentially unchanged: Type 1, 16; Type 2, 6; Type 3, 4; Type 4, 3; Type 5, 2; Type 6, 8.

[e] Two clauses contained multiple predicates in which one predicate was marked with a cardinal device and one with a non-cardinal device.

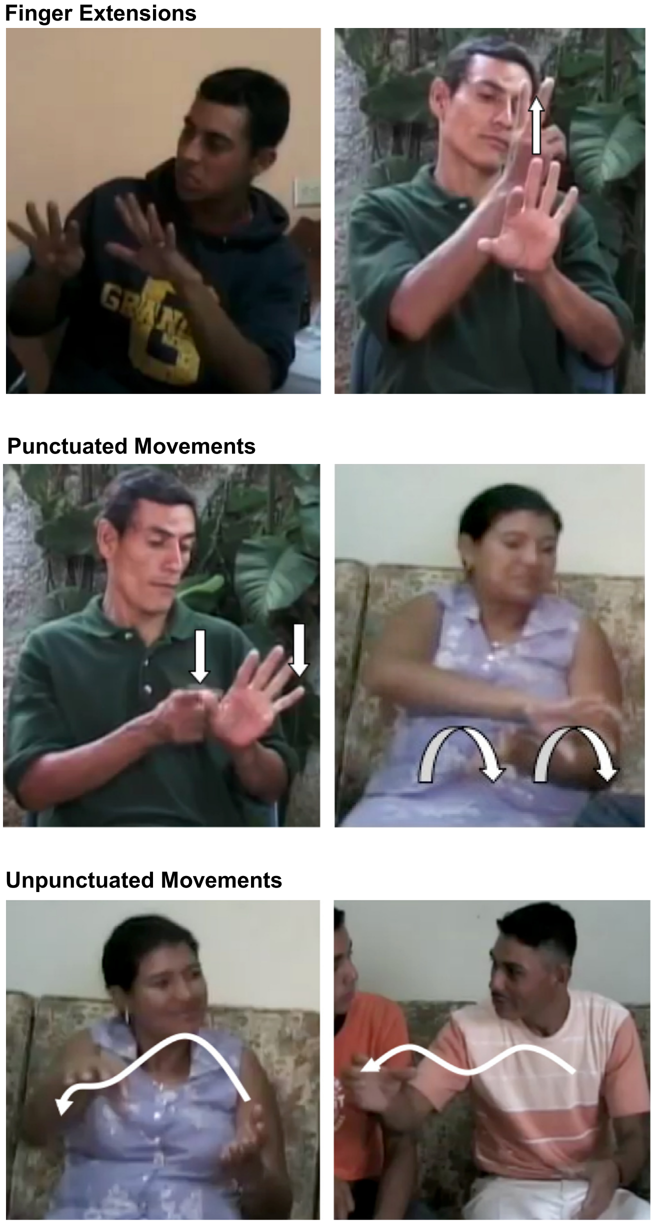

Fig. 1. Examples of clauses containing the three number devices that the homesigners used. Top pictures depict FEs. Top left, a still showing the homesigner extending 9 fingers to indicate 7 frogs. The full clause is *frog nine.* Top right still shows the homesigner describing 2 flowers growing in a box, and that single gesture comprises the full clause. Middle pictures depict PMs. The middle left still shows a homesigner indicating 2 standing cups. The full clause is *this-(cup) this-(cup) upright.* The middle right still shows a homesigner describing 2 cups that have fallen. The full clause is *(cup)-fall-in-location1 (cup)-fall-in-location2 that's-it*. Bottom pictures depict UMs. The bottom left still shows a homesigner indicating 8 frogs on lily pads. The full clause is frog-on-flat-object many-located-all-over. The bottom right still shows a homesigner describing 5 cups in a row, and that single gesture comprises the full clause. Videos of each example are available in the online supplemental material; each video is subtitled, and shows the production at its original speed, followed by the same example in slow motion (20—30% of original speed). Each gesture within a glossed utterance is described by English words connected by hyphens. This convention will be used throughout the text and in the video examples.

(2) *Punctuated Movements (PMs)* were a series of discrete movements, each referring to an entity or action in the vignette. Each movement was clearly articulated and easily segmentable from the rest of the movements. Punctuated Movements could either be produced in a single space or in different spaces in front of the homesigner. Fig. 1 (middle row, right) presents an example of a Punctuated Movement device in which 2 movements, representing 2 cups falling, were produced in different spaces. Punctuated Movements could also be produced near fingers of the other hand "standing in" for a set of objects (see Fig. 1, middle left, in which the homesigner indicates the pinky and thumb of his other hand representing 2 cups).[1] "Stand-ins" could take one of two forms: (a) In *Finger stand-ins*, the hand was held either palm-in (facing the body) or palm-out, and the extended fingers represented a set of objects; points to these extended fingers were coded as Punctuated Movements. These points were often preceded by a Finger Extension indicating the quantity of the entire set. (b) In *Person stand-ins*, the homesigner pointed at himself and/or the communication partner to represent one or two characters in the vignette. This type of device was found only in Homesigner 1.

(3) *Unpunctuated Movements (UMs)* were movements produced in rapid succession with no clear break between them. Although the pauses between these iterations were much smaller than those separating the components of Punctuated Movements, they were identifiable and could be easily counted. These movements could be produced in a single space, but more often were produced in multiple spatial locations. For example, Homesigner 2 described 6 straws in a single cup by producing a *straw* gesture followed by a series of 6 smooth points in quick succession in a circle within the space standing for the cup (these straw spaces were not subsequently reused to refer to the individual straws); see also Fig. 1, bottom, in which an Unpunctuated Movement is used to represent 8 frogs on lily pads (left) or 5 cups in a row (right). In a few instances, homesigners produced an Unpunctuated Movement with both hands moving simultaneously to indicate more than one object or event (e.g., Homesigner 2 described 7 monkeys leaving by producing a *leave* gesture with two hands, each moving from the center outward).

Interestingly, the form characteristics that distinguished the homesigners' Unpunctuated Movements from their Punctuated Movements are also seen in number-related signs in American Sign Language (ASL) and other sign languages. The slight interruptions in the trajectory of an Unpunctuated Movement are reminiscent of the exhaustive form in ASL. For example, the sign GIVE-TO-EVERYONE in ASL, in which the indexic points correspond to the recipients of the giving event, is produced with an arc movement that has "one iteration at each indexic point" (Newkirk, 1998). Similarly, homesigners' Unpunctuated Movements often captured the global spatial properties of an array of objects or a series of events (as well as their multiplicity), as do analogous plural predicates in ASL (Fischer & Gough, 1978; Padden, 1988). For example, to describe 10 lily pads in a scattered configuration, most homesigners produced their Unpunctuated Movements in a quasi-random trajectory (as opposed to a straight line). The quality of movement in the homesigners' Punctuated vs. Unpunctuated Movements is also reminiscent of signs expressing multiple predicates in ASL. For example, the repetition of the movement is slow and deliberate in signs referring to small numbers of referents (e.g., three or four, comparable to homesigners' Punctuated Movements), and movement speed increases relative to the number of referents (comparable to homesigners' Unpunctuated Movements) (Baker & Cokely, 1980; Newkirk, 1998).

Homesigners often looked at their hands when producing Punctuated, but not Unpunctuated, Movements. In addition, they frequently reused the location where a Punctuated Movement for an object had been produced to refer back to that object; they did not reuse locations for Unpunctuated Movements. For borderline cases, reusing a location to refer back to the object it represented was the deciding factor in determining whether a number gesture was a Punctuated vs. an Unpunctuated Movement.

[1] Stand-ins of this sort can be found in conventional sign languages, for example, in ASL signs where a number handshape is used as a classifier representing the orientation and relative position of 1—5 specific individuals (i.e., in specific-number classifiers, Supalla, 1986).

In addition to these three types of number gestures, the homesigners produced two other types of gestures relating to quantity. In the first, "COUNT," produced by two homesigners, a finger of one hand rapidly touched all of the fingers on the other hand. The form itself had no specific numerical value and was typically followed by a Finger Extension providing a value. This gesture can be loosely translated as "I'm enumerating them." In the second, the thumb touched the tips of the other fingers of the same hand, with all fingertips facing up. This form is commonly used by hearing Nicaraguan Spanish speakers, including the communication partners of the homesigners, and means "a lot" or "full/crowded." Because these gestures were produced infrequently by the homesigners in the current study ($n = 14$ in total), we excluded them from subsequent analyses.

One author (E.S.) transcribed and glossed all of the gestures that were produced in response to each vignette, and coded each gesture as either number-related or not number-related. The total number of gestures relating to number was 542 (137 HS1, 162 HS2, 182 HS3, 61 HS4). The coder then classified those 542 gestures into number gesture types (as described earlier), and determined the number of components (fingers extended, or movements produced) in each number gesture. To assess reliability, a second coder coded a subset of the number gestures (186, or 34%) on both of these measures. Agreement between coders was 90% for classifying number gestures into the three device types, and 94% for assessing the number of components in each number gesture.

2.1.3.2. Classifying sentential clauses according to gesture order. We used previously developed criteria to determine the boundaries of the homesigners' gesture sentences (Goldin-Meadow & Mylander, 1984): two gestures were considered part of the same sentence if the hands did not relax or pause completely between gestures. We used additional manual and non-manual features found in sign languages to identify clause boundaries within each sentence. These included a larger, slower articulation of the last gesture in a clause, changes in head or body posture, and changes in facial expression (Nespor & Sandler, 1999; Sandler, 2010). In addition, we used the objects and events displayed in the stimulus items to assist us in assigning a meaning to each clause and its semantic elements (predicates and arguments; see Goldin-Meadow & Mylander, 1984).

Clauses were analyzed for order if they contained a gesture conveying a predicate (act, attribute, location) and at least one argument (actor, entity; clauses containing patients or endpoints were too infrequent in the responses to this stimulus set to analyze for order). We thus conducted order analyses on actor-act (*frogs jump*), entity-attribute (*cups are upright*), and entity-location (*boxes are located in a row*) clauses. We excluded all clauses that contained bracketing, that is, clauses in which the argument was produced both before and after the predicate ($n = 35$, 3 for HS1, 23 for HS2, 6 for HS3, 3 for HS4) or the predicate was produced both before and after the argument ($n = 5$, 2 for HS1, 3 for HS2). Such forms are common in conventional sign languages (see Fischer & Janis, 1990), but were excluded from this analysis because they are not straightforward to analyze with respect to word order. As is also common in sign languages, the homesigners produced many predicates that incorporated arguments; unless there was at least one argument expressed as a separate gesture, these clauses were excluded from the order analysis.

One of the authors (M.C.) determined the predicate type for each clause (act, attribute, location, or none); assigned a semantic role to each gesture (act, attribute, location, actor, patient, entity, or other); and classified relevant clauses according to gesture order (e.g. actor-act, act-actor, etc.). A second coder then analyzed a subset of the data (45 clauses containing 123 gestures) for these same dimensions; agreement between coders was high: 98% for predicate type; 100% for semantic roles; and 100% for clause orders.

2.2. Results

Homesigners readily understood the task and provided detailed descriptions of the objects and events in the vignettes. The homesigners' descriptions of the 10 vignettes contained a total of 1663 gestures (270 HS1, 403 HS2, 570 HS3, 420 HS4). The descriptions contained a total of 726 clause units (137 HS1, 150 HS2, 215 HS3, 224 HS4), with a mean of 18.2 clauses per vignette[2] (13.7 HS1, 15.0 HS2,

[2] An utterance could contain more than one clause unit.

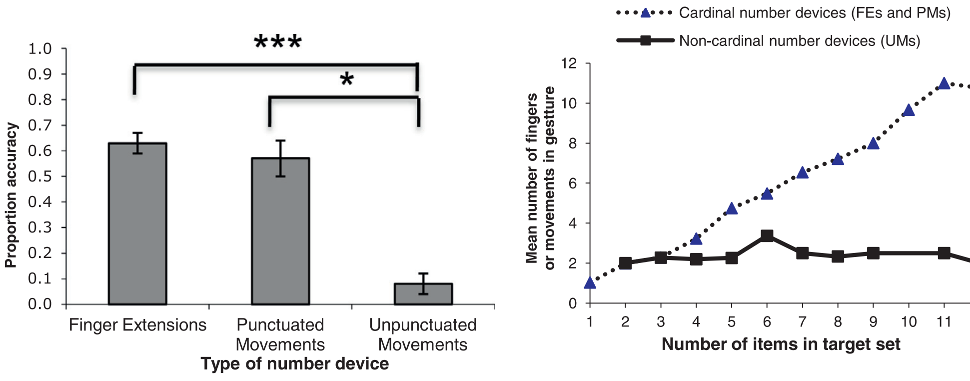

Fig. 2. Accuracy of number devices. Bars on left indicate proportion correct averaged across homesigners; error bars indicate SE. FEs and PMs were significantly more accurate than UMs, and not different from each other. Lines on right indicate the average number of components (fingers extended or movements produced) in cardinal devices (FEs, PMs) and non-cardinal devices (UMs) as a function of target set size, averaged per participant. Number of components increased systematically with increasing target values for cardinal forms, but not for non-cardinal forms. Note that the non-cardinal multiple form was never used for a target set size of 1. Accuracy results follow the same pattern if the PMs ($n = 72$) are removed from the non-cardinal category.

21.5 HS3, 22.4 HS4). The number of gestures per clause ranged from 1 to 8, with an average of 2.3 gestures per clause (2.0 HS1, 2.7 HS2, 2.7 HS3, 1.9 HS4).

2.2.1. Homesigners' number devices in relation to the referential world

We found that all four homesigners used the three main types of number gestures to communicate about number: *Fingers Extended* ($n = 243$, 56 HS1, 83 HS2, 81 HS3, 23 HS4); *Punctuated Movements* ($n = 72$, 15 HS1, 24 HS2, 27 HS3, 6 HS4), and *Unpunctuated Movements* ($n = 85$, 33 HS1, 24 HS2, 16 HS3, 12 HS4). This total, 400, represents only those number gestures for which a specific target quantity could be identified unambiguously using the vignette events, and is therefore smaller than the total of number devices reported earlier. Number devices that were produced in isolation (e.g., FIVE) or in combination with other gestures that did not unambiguously pick out a target event were excluded from this analysis ($n = 128$, 26 HS1, 33 HS2, 51 HS3, 18 HS4).[3]

We know from previous work (Spaepen et al., 2011) that homesigners are roughly accurate in their use of Finger Extensions, holding up exactly the right number of fingers to convey small numbers and approximately the right number of fingers to convey large numbers. However, because many established sign languages have plural devices in which sign form does *not* correspond to number of objects or actions, we could not assume *a priori* that the homesigners were trying to accurately map gesture form onto number of target items in all three of their different types of number gestures. We therefore began by asking whether homesigners were as accurate in their use of Punctuated and Unpunctuated Movements as they were in their use of Finger Extensions. We counted a gesture as accurate if the number of fingers or movements in the gesture matched the number of objects or events depicted in the vignette. Using a one-way ANOVA with type of number gesture (Finger Extensions, Punctuated Movements, Unpunctuated Movements) as the within-subjects factor, we found that the three types of gestures differed with respect to accuracy, $F(2, 9) = 34.32$, $p < .0001$. Finger Extensions ($M = .63$, .54 HS1, .63 HS2, .74 HS3, .61 HS4) and Punctuated Movements ($M = .57$, .47 HS1, .54 HS2, .78 HS3, .50 HS4) were both significantly more accurate than Unpunctuated Movements ($M = .08$, .15 HS1, .04 HS2, .13 HS3, .00 HS4), p's $< .01$, and did not differ from each other (Tukey HSD Test) (Fig. 2, left). If we relax our criterion for accuracy and consider responses to be accurate if they are one off from the target value, we find that the pattern still holds—Finger Extensions ($M = .87$, .84 HS1, .96 HS2, .99 HS3, .70 HS4) and Punctuated Movements ($M = .71$, .73 HS1, .67 HS2, .93 HS3, .50 HS4) were

[3] The question we address in our first analysis depends on knowing the value expressed by the homesigner; we therefore had to exclude number gestures for which we could not definitively establish an intended target value.

significantly more accurate than Unpunctuated Movements ($M = .27$, .58 HS1, .13 HS2, .38 HS3, .00 HS4), $F(2, 9) = 9.92$, $p = .005$. Again, Finger Extensions and Punctuated Movements did not differ significantly from each other, and both were significantly more accurate than Unpunctuated Movements, $p < .01$ for FEs and $p < .05$ for PMs (Tukey HSD Test).

The homesigners thus seem to be striving for accuracy when they use Finger Extensions and Punctuated Movements, but not when they use Unpunctuated Movements. The number of extended fingers or movements in a Finger Extension or Punctuated Movement often accurately portrayed the actual number of objects (see, for example, Fig. 1, top right Finger Extension, 2 fingers for 2 flowers; middle left Punctuated Movement, 2 movements for 2 cups; middle right Punctuated Movement, 2 movements for 2 cups). Moreover, when Finger Extensions and Punctuated Movements were incorrect, they closely approximated the actual number of objects (see Fig. 1, top left Finger Extension, 9 fingers for 7 cups). In contrast, although the number of movements in an Unpunctuated Movement could be accurate or a close approximation of the actual number of objects (Fig. 1, bottom right Unpunctuated Movement, 3 movements for 5 cups), the number of movements could also vary dramatically from the actual number of objects (bottom left Unpunctuated Movement, 3 movements for 8 frogs).

On the basis of this difference, we hypothesized that Finger Extensions and Punctuated Movements function like cardinal numerical devices, referring to specific values, and Unpunctuated Movements function like non-cardinal numerical devices, referring to non-singular, but unspecified, magnitudes (like plurals). If so, the number of fingers in Finger Extensions or movements in Punctuated Movements ought to increase systematically as a function of the increasing number of items in the target set; in this way, the gestures would have a one-to-one indexical mapping with the objects in the world (with each additional finger or movement reflecting an increase in the number of target items), and would thus function like cardinal number markers. In contrast, the number of movements in Unpunctuated Movements should *not* track the number of items in the target and would thus function like non-cardinal number markers, signaling a distinction between one and more than one rather than an exact amount.

The data in Fig. 2 (right) support this hypothesis. For each participant, the average number of fingers or movements increased systematically with increasing target values for cardinal number markers (i.e., for Finger Extensions and Punctuated Movements, the correlations were .99 HS1, .98 HS2, .99 HS3, and .91 HS4), but did not for non-cardinal number markers (i.e., for Unpunctuated Movements, the correlations were .35 HS1, .31 HS2, -.45 HS3, and .48 HS4). Fisher z tests were computed to compare the difference in correlations between cardinal and non-cardinal number marking, and were found to differ significantly, $t(3) = 3.83$, $p = .031$, two-tailed. The average number of movements in non-cardinal markers was essentially flat across target values; none of the correlations between the number of movements in the non-cardinal markers and their target values differed significantly from 0 (p's were .51, .52, .47, and .55). This pattern suggests that the non-cardinal markers were intended to convey "more than one" or "many" rather than a specific value.

Note that the distinction between the conceptual systems hypothesized to underlie representations of small (parallel individuation) and large (analogue magnitude) numbers is orthogonal to this prediction. If homesigners produce a device that functions as a cardinal marker, we would expect it to operate over quantities in both the small (1—3) and large (more than 3) ranges, as should a device that functions as a non-cardinal marker—with the exception that non-cardinal markers should *not* be used for quantities of 1. To evaluate this hypothesis, we looked at how often participants used cardinal and non-cardinal forms for different target values. Fig. 3 presents the data. Participants used cardinal forms primarily for targets below 7, but also used them for targets between 8 and 12. Non-cardinal forms were also used for targets across the entire range and also adhered to the expected exception—the non-cardinal form was *not* used for target sets of 1, providing further evidence that the form means "more than one."

2.2.2. Homesigners' number devices in relation to other gestures

We next ask whether the homesigners' number gestures function as part of their linguistic systems. If so, number gestures ought to combine with other gestures and function as parts of sentential clauses. The dataset for this analysis consisted of all clauses containing a clear predicate, with or

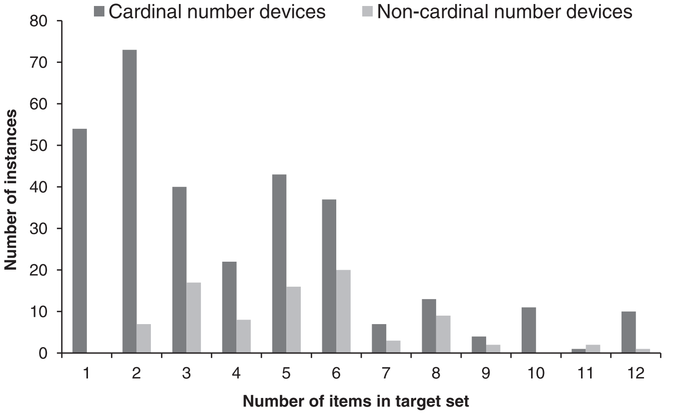

Fig. 3. Number of cardinal devices (in dark gray) and non-cardinal devices (in light gray) used by the homesigners for each target value. Both devices are used for the full range of target values, with the important exception that non-cardinal devices are never used for a target value of 1.

without a number gesture. We thus excluded the following clauses from the total ($n = 726$): 107 clauses containing only a number device, either a Finger Extension (e.g., *four*, $n = 106$, 25 HS1, 8 HS2, 21 HS3, 52 HS4) or a stand-in (i.e., a point to an extended finger, $n = 1$, HS2); 28 clauses containing a Finger Extension combined with a noun (e.g., *four BOX*, 9 HS1, 3 HS2, 9 HS3, 7 HS4); 99 clauses containing a single noun or noun phrase and no number devices (24 HS1, 10 HS2, 31 HS3, 34 HS4); 33 clauses containing a pragmatic gesture marking the end of an utterance or agreement/disagreement with the partner and no number devices (2 HS1, 0 HS2, 8 HS3, 23 HS4). The 459 clauses that remained in the analysis were first categorized according to whether they contained any type of number marking and, if so, whether that number marking functioned as an argument or a predicate. Because this analysis focused on the structure of clauses and the roles that number devices play in homesign grammar, and not on the accuracy of number devices, clauses containing number devices were included even if we could not unambiguously determine the target value or accuracy of the device.

Table 2 lists the 6 types of clauses that the homesigners produced. The table displays the semantic elements contained in each clause type, along with an example (and English gloss) of each type. Type 1 contains no overt number marking and thus is unspecified with respect to quantity. All of the remaining clause types contain number devices. A number device can be integrated into a clause in one of two ways: as an independent lexical item functioning as an argument, or as a component of the predicate.[4]

In Type 2, the number device is a free-standing lexical item that either modifies a noun (if the noun is explicitly produced, e.g., *nine frogs jump*) or stands in for a noun (if the noun is omitted, e.g., *nine jump*); the argument is thus marked for number, but the predicate is unmarked for number.

In Types 3 and 4, the number device is incorporated into the predicate, and the argument is unmarked for number. The incorporated number marking is a cardinal number marker (and indicated with a subscripted "C") in Type 3 (e.g., in *cup* $fall_{C(2)}$, the *fall* gesture was produced with two punctuated movements, indicating the two cups), and is non-cardinal (and indicated with a subscripted "NC") in Type 4 (e.g., in *frog* sit_{NC}, the *sit* gesture was articulated as a smooth unpunctuated movement with three bumps, indicating many frogs). [5] Both patterns, in which an unmarked noun phrase may receive a plural interpretation from a morphologically marked predicate, are well described by Petronio (1995) for ASL.

[4] One homesigner did incorporate number marking into a noun; he produced a reduplication of the noun MAN to indicate two men (it was clear from the stimulus that the reduplication did not describe the relative locations of the men, as they did not appear at the same time in the stimulus event). Incorporated number devices may have occurred primarily on the predicate in our dataset because the stimuli were animated events depicting actions or locative relations, not sets of to-be-named objects. ASL and other sign languages have devices that mark plurals on nominal forms, although number marking has not been found to be obligatory in any sign language studied thus far (Pfau & Steinbach, 2006).

In Types 5 and 6, both the argument and predicate are marked for number. The number marking incorporated into the predicate is cardinal in Type 5 (e.g., *four* $go_{C(4)}$, the Finger Extension *4* substituted for four sheep, playing the actor role, followed by a cardinal form, the 4 extended fingers, incorporated into the *go* predicate) and non-cardinal in Type 6 (*four be-located*$_{NC}$, the Finger Extension *4* substituted for four boxes, playing the entity role, followed by an non-cardinal form integrated into the *be-located* predicate, the hands in the shape of a box making two unpunctuated movements from left to right).

Table 2 also presents the number of clauses of each type that the homesigners produced. Note that each adult homesigner produced multiple examples of each clause type, although the distribution of types varied across homesigners. In addition, the homesigners produced a few clauses ($n = 13$) containing a cardinal or non-cardinal number device that seemed to be modifying or standing in for the argument, akin to a subordinate relative clause. For example, one homesigner produced the following sequence of four gestures to indicate that the ice cream cones once located in a particular spot were now gone: many-be-located$_{NC}$ ice-cream-cone many-be-located$_{NC}$ gone (''*the ice cream cones that were here are gone*''). Because these number devices modified arguments in a predicate-like fashion, we counted them as predicate-marked devices. Homesigners 1, 3, and 4 each produced 3 examples of this sort, and Homesigner 2 produced 4.

If number gestures are part of homesign grammar rather than an *ad hoc* way of describing quantities, they should be fully integrated into the homesigners' language—not only should they be produced in combination with other gestures (as opposed to being isolated productions), but the combinations they are in should also conform to homesign grammar. In adult Nicaraguan homesign systems, gestures for the *actor* typically precede gestures for the *act*; and gestures for the *entity* typically precede gestures for either the *attribute* or the *location* (Coppola & Newport, 2005). We thus considered these orders to be the homesigners' dominant word orders, representing their linguistic systems, in our next analyses.

We included in this analysis clauses that contained, at minimum, a gesture for the predicate and a gesture for the argument, either a noun gesture or a number gesture standing in for the noun ($n = 209$, 37 HS1, 65 HS2, 64 HS3, 43 HS4). We compared gesture order (dominant vs. non-dominant) in clauses containing no number devices (Type 1, $n = 46$, 11 HS1, 14 HS2, 10 HS3, 11 HS4); clauses containing a number device that modified or stood in for the argument (Type 2, $n = 87$, 5 HS1, 32 HS2, 38 HS3, 12 HS4*)*; clauses containing a number device that was incorporated into the predicate and the argument was expressed as a separate gesture unmarked for number (a subset of Types 3 and 4, those clauses that included an unmarked argument with a predicate, $n = 26$, 10 HS1, 6 HS2, 1 HS3, 9 HS4; 9 cardinal and 17 non-cardinal predicates); and clauses that contained number devices marking both the argument and the predicate (Types 5 and 6, $n = 50$, 11 HS1, 13 HS2, 15 HS3, 11 HS4; 22 cardinal and 28 non-cardinal predicates). Fig. 4 presents the data for each adult homesigner.[5]

Each of the four adult homesigners produced significantly more clauses that followed the dominant orders (*actor-act, entity-attribute*, or *entity-location*) than clauses that violated those orders (29 vs. 8 for HS1; 59 vs. 6 for HS2; 51 vs. 13 for HS3; 34 vs. 9 for HS4; p's < .001 in individual Sign Tests). The proportion of clauses conforming to the dominant orders did not differ significantly across the different types of clauses (i.e., no number marking, marking on just the argument, marking on just the predicate, marking on both the argument and predicate), $c2(3) = 4.5$, $p = .21$, Friedman's Rank Test. In other words, the homesigners adhered to the same orders whether or not the clause contained a number device and, if it did contain a number device, whether the device marked the argument, predicate, or both.

As we would expect if number devices are functioning as part of each homesigner's linguistic system, the position of the number device in the clause was dictated by whether it was a lexical item standing in for or modifying the argument, or a grammatical marker on the predicate. If the number device either substituted for or modified the actor or entity argument, it appeared in the first position of the clause, preceding the predicate (e.g., <u>*two*</u> *cup fall*; <u>*three*</u> *be-located*). In contrast, if the number device was incorporated into the act, attribute, or locative predicate, it appeared in second position,

[5] If we include only the responses given on the first set of items for HS4, we find the patterns described below are unchanged. As described earlier, we included data from the second set of items for HS4 so that we would have sufficient numbers to conduct statistical analyses.

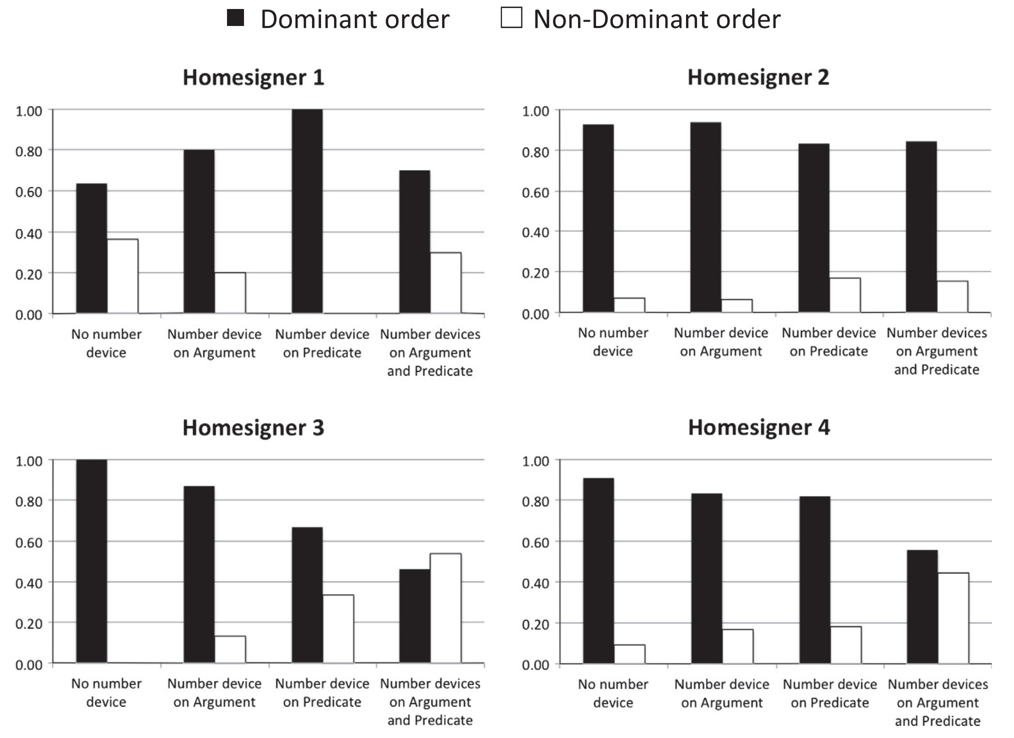

Fig. 4. The proportion of clauses that conformed to the dominant orders (black bars) produced by each homesigner, classified according to clause type (see Table 2). Homesigners preferred the dominant order (actor-act; entity-attribute; entity-location) for all clause types, whether or not the clause contained a number device and, if it contained a number device, whether it marked the argument, predicate, or both, with one exception (Homesigner 3 for clauses containing number devices on both the argument and predicate).

after the argument (e.g., *two flower* *grow*$_{NC}$; *box* *be-located*$_{C(4)}$. Thus, number devices were fully integrated into homesign clauses, and those clauses displayed the same ordering patterns that characterized clauses without number devices.

2.2.3. Where do number devices come from? The role of communication partners

Each of the homesigners had interacted for many years with the hearing communication partner who participated in the study. We next asked whether the communication partners used the three number devices produced by the homesigners. If so, we then asked whether the partners' accuracy patterns mirrored those of the homesigners' and whether their gesture combinations displayed the same structural patterns as the homesigners'. Since hearing speakers routinely extend their fingers when gesturing about number, we expected the communication partners to use cardinal number devices in their gestural descriptions of the vignettes, and these gestures might have served as a model for the homesigners' cardinal forms over development. In contrast, the non-cardinal number devices that the homesigners produced have not been reported in the gestures hearing speakers produce, and therefore might have been the homesigners' own invention.

The communication partners' descriptions of the 10 vignettes contained a total of 201 clause units (a mean of 50 per vignette, 62 for Homesign partner 1, HSP1, 65 for HSP2, 43 for HSP3, 31 for HSP4), containing up to 8 gestures per vignette; their total number of gestures was 466 (M = 117, 151 HSP1, 167 HSP2, 94 HSP3, 54 HSP4), and the average number of gestures per clause unit was 2.3 (2.4 HSP1, 2.6 HSP2, 2.2 HSP3, 1.7 HSP4).

2.2.3.1. Communication partners' number devices in relation to the referential world. Each homesigner's communication partner produced all three types of number devices in their gestured narratives: both cardinal forms (Finger Extensions, $n = 123$, 28 HSP1, 49 HSP2, 24 HSP3, 22 HSP4, and Punctuated Movements, $n = 31$, 16 HSP1, 9 HSP2, 5 HSP3, 1 HSP4) and non-cardinal forms (Unpunctuated Movements, $n = 30$, 11 HSP1, 11 HSP2, 4 HSP3, 4 HSP4). Recall that these two types of number devices were identified on the basis of form: cardinal devices have discrete finger extensions or discrete/punctuated internal movements; non-cardinal devices have smooth/unpunctuated internal movements. Like the homesigners, the communication partners were more likely to be accurate (i.e., to use the correct number of fingers or movements) when producing cardinal forms—Finger Extensions ($M = .96$, SD = .03) and Punctuated Movements ($M = .89$, SD = .08)—than non-cardinal forms, Unpunctuated Movements ($M = .35$, SD = .25), $F(2, 9) = 19.1$, $p < .001$. Finger Extensions and Punctuated Movements were both significantly more accurate than Unpunctuated Movements, p's < .01, and did not differ from each other (Tukey HSD Test).

Interestingly, however, if we relax our criterion for accuracy and consider responses to be accurate if they are one off from the target value, we find a somewhat different pattern for the homesigners and their communication partners. Accuracy was still higher for the cardinal than the non-cardinal forms with the relaxed criterion in both groups (communication partners: cardinal $M = .96$ vs. non-cardinal $M = .69$; homesigners: cardinal $M = .85$ vs. non-cardinal $M = .27$). However, the difference between accuracy for the two forms was significantly smaller in the communication partners than in the homesigners: on average, the proportion correct for cardinal minus the proportion correct for non-cardinal was .27 (SD = .29) for the communication partners, compared to .58 (SD=.24) for the homesigners, Mann—Whitney $U = 2$, $p = .057$, one-tailed. The communication partners seem to be striving for accuracy when they use both cardinal and non-cardinal forms, whereas the homesigners seem to be striving for accuracy only for cardinal forms, allowing their non-cardinal forms to mean "more than one" rather than a specified number. This difference suggests that homesigners' gestures contain two distinct systems for expressing number, whereas the communication partners' gestures may not.

2.2.3.2. Communication Partners' number devices in relation to other gestures. Table 2 displays the number of clauses of each type that the homesigners' communication partners produced in their gestures. Partners 1, 2, and 3 produced all 6 clause types, but partner 4 produced only 4 of the 6 types; she did not produce any sentences in which a cardinal number device was incorporated into the predicate (i.e., Types 3 or 5). In addition, recall that all four of the homesigners produced gesture sentences in which a cardinal or non-cardinal number device modified or stood in for the argument, akin to a subordinate relative clause (e.g., "*the ice cream cones that were here are gone*"). In contrast, none of the communication partners produced any number devices that functioned in this way.

An analysis of the number of vignettes that elicited cardinal and non-cardinal number devices suggests a difference between homesigners and communication partners in non-cardinal devices (see Fig. 5). The participants, homesigners and communication partners alike, produced cardinal number devices in all 10 vignettes (the one exception was homesigner 1, who failed to use cardinal number gestures on 1 of the 10 vignettes). Non-cardinal number devices were used less consistently by all of the participants, but the homesigners used non-cardinal number devices when describing significantly more vignettes than their communication partners, $M = 6.5$ (SD = 1.7) vs. 2.5 (SD = 1.3), $t(3) = 9.798$, $p = .002$, paired samples two-tailed t-test. This pattern held for each homesigner-partner pair (see Fig. 5).

The communication partners produced a relatively small number of clauses that could be analyzed for order (i.e., combinations of argument and predicate gestures): $n = 54$ total, 13 without number devices and 41 with number devices for the partners, compared to $n = 209$, 46 without number devices and 163 with number devices for the homesigners. All four of the communication partners displayed the homesigners' dominant orders in the clauses they produced *without* number marking ($M = 1.00$, for the partners, M=.87, for homesigners). Partners also tended to follow this pattern in the clauses they produced *with* number marking (.67 of the 15 relevant sentences followed the order for HSP1, .70 of 20 sentences for HSP2, 1.00 of 3 sentences for HSP3, and .67 of 3 sentences for HSP4).

We have seen that adult homesigners, who have been using their gesture systems as their primary means of communication for their entire lives, not only used gestures to communicate about

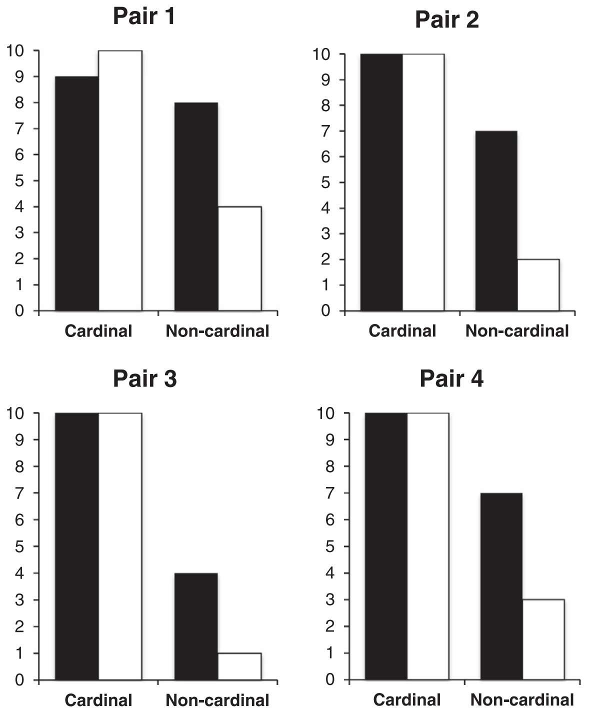

Fig. 5. Number of vignettes (out of 10) that elicited cardinal and non-cardinal number devices from homesigners (black bars) and their communication partners (white bars). Participants produced cardinal number devices in response to all 10 vignettes, but homesigners produced non-cardinal number devices in response to significantly more vignettes than their communication partners.

quantities, but also fully integrated their number gesture into their homesign systems. The communication partners with whom the homesigners routinely interact also used gesture to communicate about quantities, and did so in roughly the same ways as the homesigners. These parallels might reflect the fact that the communication partners invented the number devices, which were then copied by the homesigners. But the parallels could also indicate that the homesigners created the devices, which were picked up by the communication partners, or that the two created the devices together. To better understand the development of these number devices, we tested a child homesigner and his hearing mother using the data collection and data analysis procedures developed in Study 1.

3. Study 2: Generating number devices over development: Number gestures in a child homesigner and his mother

3.1. Method

3.1.1. Participants

The deaf homesigning child was 7 years, 4 months old and his mother was 27 years old. The child is profoundly deaf, with a bilateral hearing loss greater than 90 dB, and did not use any type of amplification (hearing aid or cochlear implant). He had not had any formal schooling, but had sporadically attended therapy sessions at an organization serving parents who had children with special needs; the organization was based in the nearest city, about 45 min away. Despite these therapy sessions, the child had not acquired any usable spoken Spanish, nor had the child been exposed to or acquired Nicaraguan Sign Language (NSL). His mother is a hearing, monolingual Spanish speaker, and knew no NSL or any other sign language. However, like the partners of the adult homesigners, his mother did use gestures when interacting with him.

3.1.2. Materials and procedure

The child and his mother were tested in an identical fashion as the adult homesigners and their communication partners in Study 1. The child, like the adult homesigners, described the vignettes twice; both sets of his responses are included in the current analyses. His mother, like the other communication partners, was tested once. The data were coded and analyzed as in Study 1.

The child homesigner readily understood and succeeded in the vignette description task. His descriptions of the 20 vignettes contained a total of 188 clause units (a mean of 9.4 per vignette), each containing up to 7 gestures for a given vignette, although many contained fewer. His total number of gestures was 366, and his average number of gestures per clause unit was 2.0. In describing 10 vignettes, the child's mother produced 38 clause units, each containing up to 3 gestures. Her total number of gestures was 52, and her average number of gestures per clause unit was 1.4.

We assessed the reliability of our coding procedures. For the analysis of accuracy in number devices, one coder transcribed and glossed all of the gestures that the child homesigner and his mother produced in response to each vignette, coded each gesture as number-related or not number-related, and then classified each number gesture according to type (Finger Extension, Punctuated Movement, or Unpunctuated Movement). To assess reliability, a second coder coded a subset of responses on these dimensions. Agreement between the two coders was 97% both for classifying number gestures into the three types of devices and for determining the number of components (i.e., number of fingers extended or internal movements) in each number device. For the clausal analyses, the first coder also determined the predicate type for each clause (act, attribute, location, or none); assigned a semantic role to each gesture (act, attribute, location, actor, patient, entity, or other); and classified the relevant clauses according to gesture order (dominant, non-dominant, or other). One of the authors (M.C.) then coded a subset of the data (32 clauses containing 93 gestures) on these same dimensions. Agreement between coders was high: 91% for determining predicate type (act, attribute, location, or none); 86% for assigning semantic roles (act, attribute, location, actor, patient, entity, or other), and 100% for categorizing clause orders as dominant, non-dominant, or other.

3.2. Results

3.2.1. Number devices in relation to the referential world

The child homesigner produced all three types of number devices: Finger Extensions ($n = 114$), Punctuated Movements ($n = 3$), and Unpunctuated Movements ($n = 5$). His mother produced 29 number gestures, 28 of which were Finger Extensions; she also produced 1 instance of an Unpunctuated Movement.

We first asked whether the child homesigner was as accurate in his use of Punctuated and Unpunctuated Movements as he was in his use of Finger Extensions. We again counted a gesture as accurate if the number of fingers or movements in the gesture matched the number of objects or events depicted in the vignette. The child was more accurate in his Finger Extensions (.61 correct, 70 out of 114) and Punctuated Movements (1.00 correct, 3 out of 3) than in his Unpunctuated Movements (.20 correct, 1 out of 5) (see Fig. 6, left). Overall, the proportion of times that the number of components in the homesigning child's number devices exactly matched the target set was .64 for cardinal forms and .20 for non-cardinal forms ($p = .077$, Fisher's exact test). By comparison, the homesigner's hearing mother was somewhat more accurate than her child for cardinal forms (.86), and produced only one non-cardinal form, on which she was not accurate.

Fig. 6 (right) presents the average number of fingers or movements that the child homesigner produced as a function of target value. As in the adult homesigners, number of fingers or movements increased steadily with increases in target value for cardinal number devices (Finger Extensions and Punctuated Movements), but not for non-cardinal number devices (Unpunctuated Movements). The average number of movements in non-cardinal forms was essentially flat across target values, suggesting that the child homesigner too used movements to convey "more than one" or "many" rather than a specific value.

Like the adult homesigners, the child homesigner used his cardinal devices for the full range of targets, including target set sizes of 1. Importantly, however, and again like the adult homesigners, he

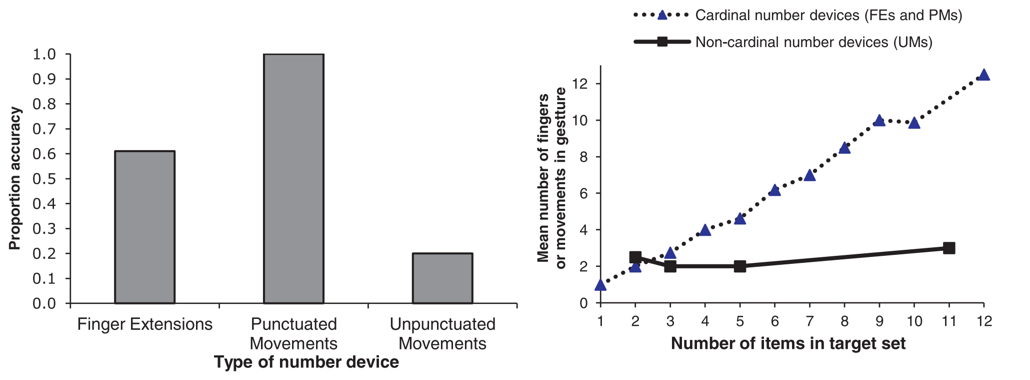

Fig. 6. Accuracy of number devices for the child homesigner. Bars on left indicate the proportion correct for each target value. Lines on right indicate the average number of components (fingers extended or movements produced) in cardinal devices (FEs, PMs) and non-cardinal devices (UMs) as a function of target set size.

used his non-cardinal devices only for targets greater than 1, suggesting that he too used this device to mean "more than one."

3.2.2. Number devices in relation to other gestures

Table 3 displays the number of clauses of each type that the child homesigner and his mother produced in their gestures. Note that the child produced at least one instance of all 6 types of clauses, including instances where the lexical number modified a noun (e.g., *two bear sit chair*). In contrast, the homesigner's mother produced many clauses that did not contain a number device (Type 1) and many containing lexical numbers (Type 2). However, her lexical numbers never modified a noun (i.e., she produced *three eat* rather than *three monkeys eat)* and she produced no instances of Types 3, 4, or 5, and only one example of Type 6, *grow*$_{NC}$ *five* (i.e., a clause containing number marking on both the argument and predicate).

Finally, we asked whether the child homesigner's clauses adhered to the order patterns found in the adult homesigners' gestures. We found that .70 (14 out of 20) of the child's clauses containing

Table 3

Types of clauses produced by the child homesigner and his hearing mother, classified according to the role(s) assumed by the number device[a].

Number marking[b]		Clause elements[c]	Examples	Gloss	Child homesigner	Mother
No number marking	1	(N) P	ELEPHANT WALK	One or many elephants walk.	52	8
Lexical number	2	C (N) P	SEVEN EAT LEAVE	Seven (monkeys) eat and leave.	78	24
Number-marked predicate	3	(N) P$_C$	GROW$_{C(4)}$ SMALL	Four small (flowers) grow.	5	0
	4	(N) P$_{NC}$	SMALL GROW$_{NC}$	Many small (flowers) grow.	3	0
Lexical number + number-marked predicate	5	C (N) P$_C$	FIVE DRINK$_{C(5)}$	Five (birds) drink.	1	0
	6	C (N) P$_{NC}$	TWO FALL$_{NC}$	Two (cups) fall.	1	1

[a] P = Predicate; P$_C$ = Predicate with a cardinal number marker, with the number in parentheses indicating the number of fingers or movements incorporated into the predicate; P$_{NC}$ = Predicate with a non-cardinal number marker.

[b] Lexical number signs (C = cardinal) are finger extensions that either modify or substitute for a nominal, or points to extended fingers that function as nominals (stand-ins).

[c] The parentheses around the noun (N) indicate that it is optional; participants can either explicitly produce a sign for the N (as in example 1) or use a lexical number sign (C) as a substitute for the N (as in examples 2, 5, and 6).

an argument and a predicate followed the orders found in the adult homesigners' clauses, $p = .057$, one-tailed sign test; there was no difference between clauses that did not contain a number device (.75, 8 out of 12) and clauses that did (.75, 6 out of 8), although the numbers in both sets are small. In contrast, the homesigning child's hearing mother showed no order bias in the few relevant clauses that she produced. One out of 4 (.25) of her clauses containing an argument and a predicate followed the adult homesigners' dominant order; in particular, the 1 non-number clause the mother produced did not adhere to the dominant order, 1 of her 3 (.33) number clauses did (the one clause the hearing mother produced that contained a Unpunctuated Movement, as opposed to a Finger Extension, did *not* follow the dominant order).

In sum, the child homesigner's gestures resembled the adult homesigners' gestures in every respect: (1) He produced all three types of number devices. (2) The form of his Finger Extension and Punctuated Movement gestures mapped onto the target numbers they represented relatively accurately and thus warranted the label *cardinal*; his Unpunctuated Movement gestures did not and were thus *non-cardinal*. (3) He used his cardinal number gestures for the full range of target numbers (from 1 to 12); he restricted the range to which he applied his non-cardinal number gestures to those greater than 1, suggesting that these forms meant "more than one." (4) He incorporated his number gestures into his homesign system, producing the same 5 types of clauses containing number marking as the adult homesigners. (5) He adhered to the dominant word order patterns found in the adult homesigners in the clauses he produced that did and did not contain number devices.

In contrast, all but one of the number gestures that the child's hearing mother produced were lexical numbers (i.e., Finger Extensions)—the kinds of gestures hearing speakers routinely produce when referring to number. She used these number gestures relatively accurately and, on occasion, combined them with other gestures. However, she produced no instances of Punctuated Movement gestures and only one Unpunctuated Movement gesture. Thus, the homesigner's hearing mother failed to produce 3 of the 5 types of clauses with number gestures that both the child and adult homesigners produced. Finally, the one clause combination that she produced containing a number-marked predicate and a lexical number did not follow the dominant order used by both the child and adult homesigners.

3.3. General discussion

Homesign systems have been shown to have many, though not all, of the properties found in natural languages (see, for example, Goldin-Meadow, 2003 as well as more recent research on child and adult homesign systems reviewed above). Previous work has shown that homesigners use extended fingers to communicate about quantities, and that these finger extensions are completely accurate for targets of 1, 2, and 3 and approximately accurate for quantities above 3 (Spaepen et al., 2011).

This study describes in detail, for the first time, two additional devices that homesigners use to communicate about number: punctuated movements, which, like finger extensions, attempt to specify the number of items in the target set, that is, *cardinal* number markers; and unpunctuated movements, which do not even attempt to specify the exact quantity in the target set, *non-cardinal* number markers. Our study is also the first to demonstrate that all of these number devices are fully integrated into homesign gesture systems and, in this sense, are linguistic. Although there was great variation in how often the four homesigners gestured (e.g., HS4 produced fewer gestures and number devices than the other three adult homesigners), the overall patterns were the same for all four homesigners. Indeed, the data for Homesigner 4 underscore the point that these patterns are robust despite variation in amount of gesture.

Because homesigners have not been exposed to conventional language, the way they communicate about number has the potential to offer insight into the biases humans impose on how number is conveyed in language. We focus our discussion around two types of biases: (1) How number gestures are mapped onto numbers of objects in the world; that is, the biases humans have with respect to referential number. (2) How number gestures are used with respect to other types of gestures; that is, the biases humans have with respect to linguistic number. We end by exploring the input that might contribute to the development of numerical devices in homesign.

3.4. Biases with respect to referential number: Cardinal and non-cardinal number devices

All of the homesigners we studied produced gestures, which we refer to as *cardinal number devices,* that specify as precisely as possible the exact number of objects described (see Spaepen et al., 2011). The homesigners either extended an array of fingers or produced a series of punctuated movements that mapped onto the number of items in the vignettes. For example, four punctuated movements of the hands, articulated in a lateral line in front of the body, referred to a row of four flower pots (*four-be-located*). Cardinal number devices are thus relatively transparent in how they express number meaning.

The homesigners also used a second number device, which we refer to as *non-cardinal number*, that allowed them to indicate more than one without committing to how many more. For example, a fluid unpunctuated movement containing two "bumps," glossed as *more-than-one-be-located*, was also used to describe the row of four flower pots. A device that allows this type of imprecision seems as though it would be particularly useful for large numbers that are difficult to count. However, all of the homesigners (including the child homesigner) used non-cardinal number devices for numbers as small as 2 or 3 (i.e., for numbers that they were able to quantify correctly, Spaepen et al., 2011). Thus, homesigners are not using the non-cardinal form because they are unable to specify sets with large numbers. The homesigners use the non-cardinal number device for any number as long as it is larger than 1. Moreover, they incorporate this device into the predicate, thus making it morphological. These characteristics suggest that the non-cardinal device may be functioning as a plural marker on the verb in these homesign systems.

It is important to note that the homesigners' non-cardinal forms do not all display the same motion trajectory. Rather, what these forms have in common is a smooth movement containing approximately two "bumps," representing "many" or "more than one"; the particular trajectory that the movement follows is determined by the spatial arrangement of the multiple objects (see the two examples of unpunctuated movements in the bottom row of Fig. 1). Similar devices are found in conventional sign languages (cf. Bahan, 1996). For example, Engberg-Pedersen (1993) analyzes comparable forms in Danish Sign Language as *distribution* morphemes, which denote the location and configuration of an unspecified number of entities. Similarly, in American Sign Language (ASL), the form of the plural marker cannot be generalized across all predicates, in part because of the close connection between number and spatial location marking in sign languages (see Cormier, 2002, who suggests that this close connection is comparable to the tight link between number and person in spoken languages, cf. Forchheimer, 1953).

The number of unpunctuated movements in the homesigners' non-cardinal number gestures does not map neatly onto the number of objects that the gesture represents. As a result, the form of a non-cardinal number gesture maps onto the number of items it represents less transparently than the form of a cardinal number gesture and, accordingly, sacrifices iconicity. We see a similar loss of iconicity in conventional sign languages in plural verbs (e.g., ASL, Cormier, 2002; British Sign Language, Sutton-Spence & Woll, 1999; German Sign Language, Pfau & Steinbach, 2006) and plural forms of pronouns (Klima & Bellugi, 1979). It is interesting that we see the seeds of this process not only in adult homesigners, but also in the homesigns of a 7-year-old child.

3.5. Biases with respect to linguistic number: Integrating number devices into sentences

We found that the homesigners incorporated both their cardinal and non-cardinal forms into their gesture sentences. They used cardinal number devices as stand-alone lexical items to modify or stand in for a noun playing an argument role (e.g., *four sheep go*; *four go*, Type 2 sentences in Table 2). They also incorporated both cardinal and non-cardinal number devices into locatives or verbs playing a predicate role in the clause (e.g., *box four-be-located* or *cup two-fall*, Type 3; *straw more-than-one-in-a-circle* or *flower more-than-one-grow*, Type 4). Finally, as is found in many natural languages, homesigners used lexical number along with number marking on the predicate (e.g., *two flower two-grow*, Type 5; *four box more-than-one-in-a-row,* Type 6).

Importantly, when the homesigners used their cardinal and non-cardinal number devices as either arguments and/or predicates in clauses, those clauses followed the same word orders as clauses that did not contain number devices. In other words, sentences containing number devices followed the patterns characteristic of the homesigners' systems.[6] We have used semantic terms to characterize the homesigners' orders (*actor-act*, *entity-location*, *entity-attribute*), but other characterizations are possible. For example, it is possible to ground the orders in basic information structures (e.g., indicating the object on which an action is to be done, *topic,* before describing the action, *comment*) or to describe them in terms of syntactic categories (e.g., *subject-predicate*). Indeed, there is evidence from previous work that the homesigners' ordering patterns are best described in syntactic terms. Coppola and Newport (2005) manipulated the information structure of stimulus events in short narratives, and elicited descriptions of these events from three of the four homesigners in our study. The most parsimonious description of the noun phrases that the homesigners produced in clause-initial position made use of the relation *subject,* not *topic*. Note, however, that no matter which categories we use to describe ordering patterns in the homesigners' gestures, it is clear that the devices they use to convey number are not merely isolated labels for numerical sets, but are fully integrated into their gesture systems and, in this sense, are linguistic.

Conventional sign languages also allow both cardinal and non-cardinal number devices to be integrated into predicates (Fischer & Gough, 1978/1980; Engberg-Pedersen, 1993; Newkirk, 1998; Padden, 1988; Pfau & Steinbach, 2006). For example, in terms of cardinal forms, number handshapes (akin to finger extensions in our homesigners) can be incorporated into temporal expressions in ASL (3-DAYS, 5-YEARS, Stokoe, Casterline, & Croneberg, 1965); into action, locative, and measure predicates in Taiwan Sign Language, Korean Sign Language, and Japanese Sign Language (5-ENTER-CAR, 10-ON-TREE, FIRST-GRADE, Fischer, Hung, & Liu, 2011); and into locative predicates in Turkish Sign Language (3-IN-A-LINE, Özyürek, Zwitserlood, & Perniss, 2010) (see also Heyerick et al., 2011, for descriptions and online videos of examples in Flemish Sign Language). In terms of non-cardinal forms, in ASL, multiple repetitions of a classifier for an object (a handshape that encodes the size and shape properties of the object) can be incorporated into a predicate to indicate that there are many instances of the object, and the number of repetitions in these signs does not have to match the number of referents (Baker & Cokely, 1980; Klima & Bellugi, 1979).

The similarities that we see between homesign and conventional sign languages may not be accidental. In fact, homesign may hold a special place in the historical analysis of sign languages. Many, if not all, current day sign languages have their roots in homesign (Coppola & Senghas, 2010; Cuxac, 2005; Fusellier-Souza, 2006; Goldin-Meadow, 2010). Even if developed in very different circumstances around the globe, homesigns seem to have much in common (Goldin-Meadow, 2012; Goldin-Meadow & Mylander, 1998; Goldin-Meadow et al., in press). These shared characteristics not only reflect constraints imposed by the manual modality, but also reveal linguistic capacities that all humans possess, independent of their access to conventional language, signed or spoken.

3.6. The sources of numerical devices in homesign

Robust evidence from a variety of situations demonstrates that child learners produce linguistic forms that exhibit complexity not found in their input. For example, children exposed to pidgin languages go beyond their input to produce more complex creole languages (Romaine, 1988; Sankoff & Laberge, 1973); Simon, a deaf child exposed only to the imperfect ASL of his late-learning Deaf parents produced more grammatical ASL than they did (Singleton & Newport, 2004); and deaf children who are exposed to Manually Coded English transform the sequential structure contained in this invented code into sign-like spatial forms (Supalla, 1991). In accord with these findings, many studies have identified linguistic properties in the gestures homesigners produce that are absent from, or less systematic than, the gestures produced by the hearing people who surround them. Detailed comparisons of the gestures produced by homesigners to those produced by their hearing mothers have shown that the mothers' gestures are not the source of many of the linguistic categories and structures found in the children's homesign systems; for example, noun and verb categories (Goldin-Meadow et al.,

[6] As in the current study, the dataset analyzed by Coppola and Newport (2005) did not contain enough clauses containing secondary arguments to determine whether there was a consistent ordering for patients.

1994); morphological structures (Goldin-Meadow & Mylander, 1990a, Goldin-Meadow et al., 2007); word order and production probability marking of thematic roles (Goldin-Meadow & Mylander, 1983, 1990b, 1998); and nominal constituents (Hunsicker & Goldin-Meadow, 2012).

In contrast to the deaf children observed by Goldin-Meadow and her colleagues, the adult homesigners in the current study have been interacting with their hearing communication partners for over 20 years. To explore whether the homesigners' number devices could have been borrowed from the gestures used by the hearing speakers who routinely interacted with them, we analyzed the gestures produced by the homesigners' hearing communication partners, and also observed a 7-year-old child homesigner and his mother performing the same task. All four of the communication partners and the child's hearing mother used the cardinal and non-cardinal number devices found in the homesigners' gestures, suggesting that the impetus for these terms may have come from the hearing gesturers. Given the fact that many natural languages do not have codified words for exact numbers (Hammarström, 2010), homesigners may have needed a model for the numerical terms that they use—indeed, we might expect that homesigners growing up in a community where hearing individuals do not use gesture to convey numerical quantities would *not* use their hands to indicate the numbers of objects in an array). Some form of model handed down from one generation to the next might be essential to catalyze using gesture to label numbers of items.

However, once homesigners have been exposed to gestural items of this sort, they may not need a model to be able to incorporate those number gestures into their linguistic systems. The most compelling data for this point come from the child homesigner we observed. Although both child and mother produced cardinal and non-cardinal number devices, it was the child who produced these devices in all of the types of sentential clauses found in the adult homesigners. Making number devices *linguistic* thus appears to come naturally to human communicators, even when they have not been exposed to a conventional language model.

Interestingly, when the hearing communication partners did incorporate number devices into their gesture strings, those constructions not only failed to match the homesigners' constructions, but they also could not be easily mapped onto number constructions in Spanish, their spoken language. Following obligatory number-marking patterns in Spanish, the communication partners routinely marked number on their spoken nouns and also produced spoken verbs that agreed in number with the subjects of their sentences in their everyday speech, but they rarely followed this pattern in their gestured descriptions of the stimuli in our study. These findings suggest that the communication partners' gestures have not been shaped by Spanish—nor, for that matter, have the homesigners' gestures. Indeed, the modality within which homesign is expressed appears to exert a greater influence on the structure of the homesigners' number devices than frequent interaction with Spanish speakers. In fact, no sign language studied to date has been found to require number marking on nouns and verbs, and when a verb is marked for number agreement, it is more likely to agree with the object in a sentence than with the subject (see, for example, Janis, 1995 and Meir, 2002), and thus is distinct from the pattern found in Spanish.

In principle, homesigners come equipped with all of the abilities and capacities that any child brings to the task of acquiring a language. Such abilities include statistical learning mechanisms that extract regularities from structured input. It remains an open question whether the gestural input that the homesigners receive in their worlds is sufficiently structured to support extraction of the patterns found in their number constructions. Our findings thus far offer little evidence for such a process.[7]

3.7. Homesign and emerging languages

Homesign systems provide us with a window through which we can observe properties of language that can be developed without access to a conventional language model. But the unique circumstances in Nicaragua allow us to take this phenomenon one step further, offering insight into the

[7] Note that the communication partners chosen for this task were the family members or friends who communicated most easily with each homesigner and, in this sense, represented each homesigner's best gesture model. It is not likely that other hearing people in the homesigners' environments use the number devices we have described in a more sophisticated way than their communication partners, who spend time in sustained gestural communication with the homesigners. Very little data are currently available regarding how Nicaraguan hearing individuals who do not interact with deaf people gesture about quantity.

properties of language that are *not* likely to appear in homesign. In the late 1970s and early 1980s, rapidly expanding special education programs in Nicaragua brought together in great numbers deaf children and adolescents who were, at the time, homesigners (Kegl & Iwata, 1989; Senghas, 1995). As they interacted on school buses and in the schoolyard, these students converged on a common vocabulary of signs and ways to combine those signs into sentences, and a new language—Nicaraguan Sign Language (NSL)—was born. This first cohort of NSL signers then passed the language onto the next wave of deaf individuals, cohort 2.

By observing changes made to homesign when it became a community-wide language in cohort 1, we can explore the impact that being a member of a community has on the structure of language (Coppola & Senghas, 2010; Goldin-Meadow, 2010). Indeed, cohort 1 signers have been found to display several linguistic properties not found in homesign; for example, complete segmentation of manner and path without any conflation (Senghas et al., 2004; Senghas et al., in press; Goldin-Meadow et al., in press; Özyürek, Furman, Kita, & Goldin-Meadow, in perparation); a conventionalized count list (Flaherty & Senghas, 2011); incorporation of pronouns into sentences (Coppola & Senghas, 2010); and a conventionalized lexicon (Richie, Yang, & Coppola, 2013). Taking the phenomenon even further, we can observe changes made to the system used by cohort 1 when it is learned by cohort 2, and thus gain insight into the impact that passing a newly birthed language through a new generation of learners has on linguistic structure. For example, cohort 2 signers have been found to use spatial modulations in a grammatical fashion; although cohort 1 signers also use spatial modulation, they do not use the device systematically (Senghas & Coppola, 2001). These findings suggest that having a fresh mind interpret the data may be important for the continued growth of this, and presumably other, linguistic properties.

Although homesign does not display the numerical sophistication of an established sign language or even of first and second generation NSL (Flaherty & Senghas, 2011), it does incorporate cardinal and non-cardinal devices into its sentences, as we have shown here. Our findings thus highlight the resilience of these particular linguistic devices for number.

4. Conclusion

We have found that access to conventional language input is not necessary to use devices that refer to number. Homesigners, who develop their gestural communication systems without benefit of a linguistic model, not only use cardinal number devices that convey exact numerical values, but they also use non-cardinal number devices that indicate more than one without specifying how many more. These devices are fully integrated into each individual's homesign system, serving as markers on predicates and as lexical items that either modify or stand in for arguments. Sentences that contain these numerical devices follow the same ordering rules as sentences that do not contain numerical devices, providing further evidence that the devices are linguistic.

The homesigners undoubtedly saw hearing speakers in their communities use their fingers when they talked about number, and these finger extensions are likely to have been essential in catalyzing communication about number in the homesigners. However, it is less likely that hearing speakers provided an adequate model for incorporating number into other gestures and for combining those gestures into ordered strings. In other words, it is less likely that hearing speakers provided an adequate model for making number *linguistic*. Number devices thus appear to be so fundamental to language that they do not need to be handed down in the context of a language community, but can arise even in emerging language systems.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cogpsych.2013.05.003.

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